SOILS OF THE MOWBRAY CATCHMENT

SOUTH CANTERBURY

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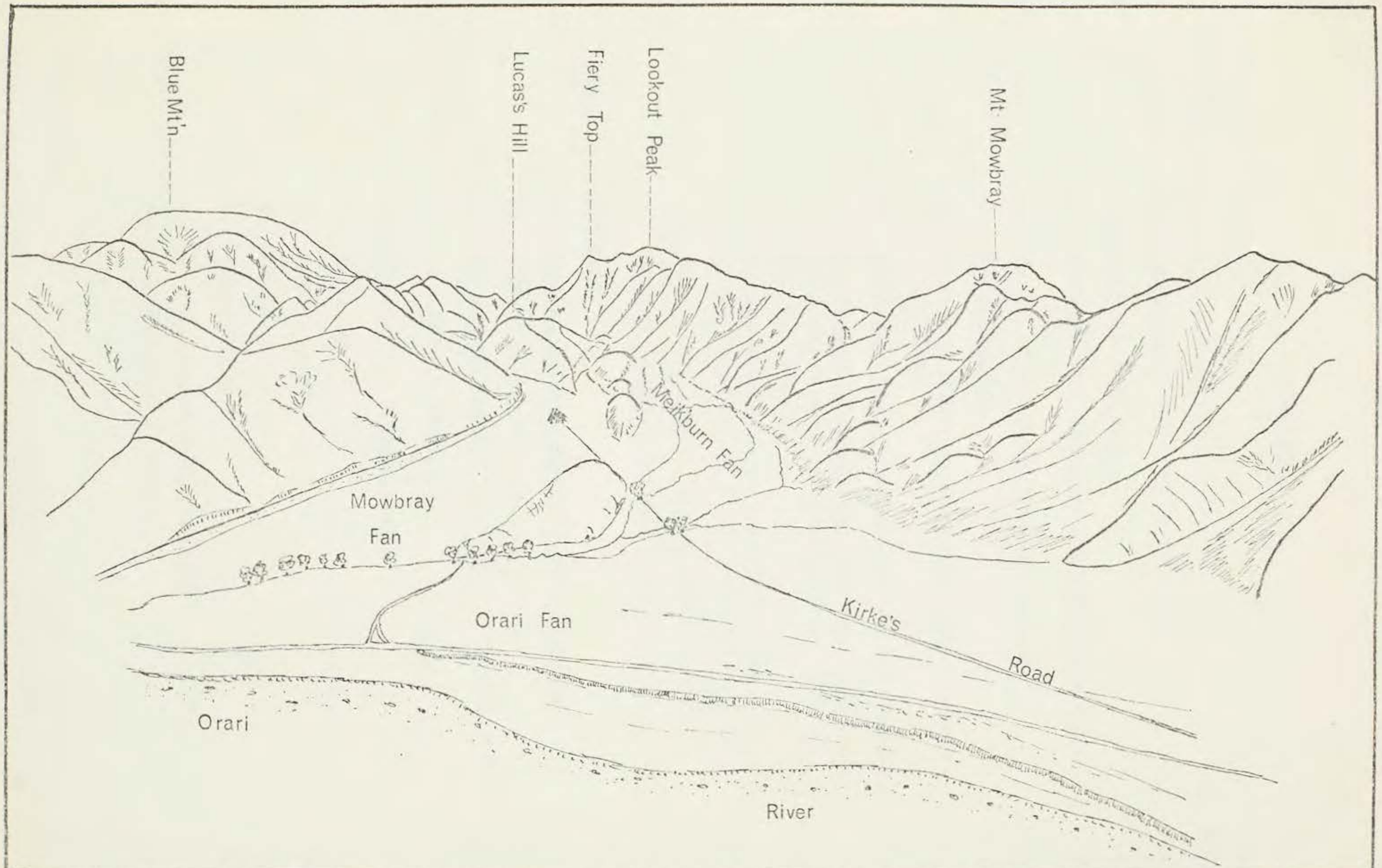


PANORAMIC VIEW OF THE MOWBRAY VALLEY SOUTH CANTERBURY

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Plates 1 and 2 were prepared by J. S. Cocks from aerial photographs supplied by New Zealand Aerial Mapping Ltd. Plates 15, 16 and 17 were prepared from colour transperancies supplied by P. J. Tonkin. All other photographs were taken by the author.

CHAPTER I

INTRODUCTION

1. GENERAL OUTLINE

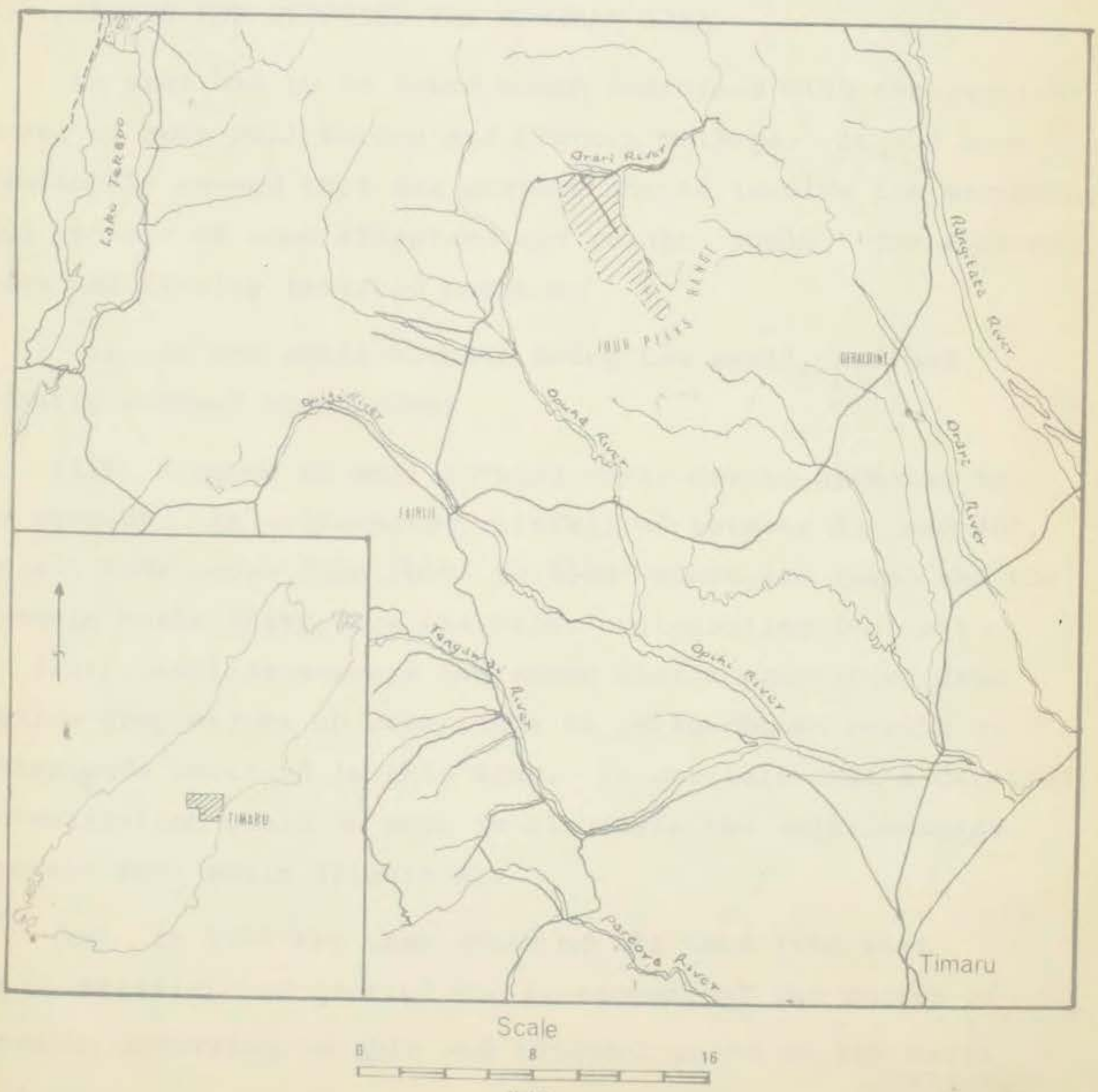
The Mowbray catchment[1] is the most south-westerly part of the Orari river watershed and lies to the north of the western end of the Four Peaks Range (see Figure 1). Access into the area is by way of the Clayton road from Fairlie. This road crosses Tripp Saddle (2300' a.s.l.) and ends at Lochaber station on the banks of the Orari river just down-stream from the confluences of the Phantom, Hewson and Orari rivers. (Figure 5).

Acland (1930) has indicated that this area was the junction of three of the very early South Canterbury stations, Clayton, Mt Fourpeaks and Orari Gorge. The boundary between Orari Gorge and Mt Fourpeaks (which it seems was included in the original lease to Tripp in 1955 - Acland p. 135) was in part the Meikleburn stream (then spelt Mickleburn). The Mt Fourpeaks-Clayton boundary ran in a straight line between the Meikleburn and Orari and crossed the western watershed just south of Tripp Pass. Harper (1967) does not agree completely with Acland and on her map of the early Orari Gorge station shows the north-western boundary of the station cutting the Mowbray catchment almost into two even sectors, one to the north of Lucas's Hill and the other to the south of this line. Today,

[1] The region studied incorporated the Mowbray and Meikleburn catchments of the Orari river (S.C. & R.C. Council, 1956). Herein the terms Mowbray catchment, ...region, ...area, are used for the collective area of the two catchments.

Part of the Mowbray Catchment
LOCALITY MAP

Fig. 1



the area surveyed is the junction of six properties, the central core being the Meikleburn Station of Mr I. H. Beattie. Part of the area covered by the Mt Fourpeaks station is still held as Four Peaks but a large area has been incorporated as Mt Mowbray and another part has been acquired by Clayton Station. Orari Gorge relinquished parts of its holding in the area to Meikleburn and Blue Mountain Stations and while the original Clayton - Orari Gorge boundary still exists the area once occupied by Clayton in the valley is now in the possession of Mr Brian Beattie, under the name of Dry Creek Station.

2. REASONS FOR STUDYING THE MOWBRAY AREA

An area had to be found which conformed with the requirements of both Soil Bureau and Lincoln College. It had been previously agreed that the project should involve the morphology and genesis of some steepland and related soils. The Mowbray area was finally selected because:

(i) it was small without being too small, and had clearly defined boundaries;

(ii) a range of soil forming environments appeared to be present. An anticipated rainfall of between 25" and 40", an altitude range from 1800' to 5500' above sea level and the terrain variability were the major contributing factors;

(iii) earlier surveys had shown that a transition from yellow-grey earths on steeplands to yellow-brown earths on steeplands occurred in this area. It was felt that a detailed investigation could do much to elucidate the relationships between such soils (figure 2).

(iv) in 1945 the then owner of the land (the late Mr J. Beattie) had queried the assessment of the degree of erosion occurring in this and adjacent parts of the Orari catchment, as shown by Gibbs et al (1945). A re-investigation of the soils in the area (Cutler pers comm.) confirmed that the erosion classification, as applied in this region, was of an adequate standard for small scale maps such as those prepared by Gibbs et al (1945). A resurvey could then provide a basis for comparative revegetation studies.

(v) finally, and of probably some importance in such studies of short duration, the area was known to the writer thus eliminating an initial familiarisation process often necessary when entering a region for the first time.

CHAPTER II

REVIEW OF LITERATURE

1. INTRODUCTION

Had this project been merely a mapping exercise it would have been a relatively simple matter to review the literature relating to the various soils found in the Mowbray area. The production of a soil map, however, has been but one facet of the whole exercise. Attempts have been made to assess the degree and intensity of weathering experienced by the soils; the influences and history affecting the genesis of the soils; the relationships between soils, landforms and surfaces of soil formation; the relationships between soil series and the range of variability likely to be encountered, at various levels of detail, within the mapping units employed.

Because of the wide spectrum of subjects covered; ranging from survey techniques, through correlations of mapping units with established series, assessment of degrees of erosion to soil chemistry and soil clay mineralogy; it has been decided to restrict this review to a few salient topics. Relevant references are cited in the body of the text and pertinent discussions on conclusions reached by these authors are recorded in the appropriate place.

It was considered advisable to construct the text in this way to:

(a) afford a more logical development of discussion in the relevant in-text place - e.g. all previous work carried out on each soil series is discussed under the heading of that soil series where it may be easily contrasted with observations made during this project.

(b) ancillary chemical, mineralogical, geological etc. data was based on techniques developed by other workers. The greater or lesser benefits of using other techniques were not investigated and consequently it was felt that no satisfactory conclusions could be drawn about the validity of such techniques.

(c) to critically review New Zealand and pertinent World literature covering a wide range of topics, such as weathering, leaching, pedogenesis, soil fertility, soil physical characteristics, factors of soil erosion, soil classification, geomorphology and landscape genesis, climatic and vegetational successions and Quarternary events; would have unnecessarily prolonged the study and the production and content of this thesis.

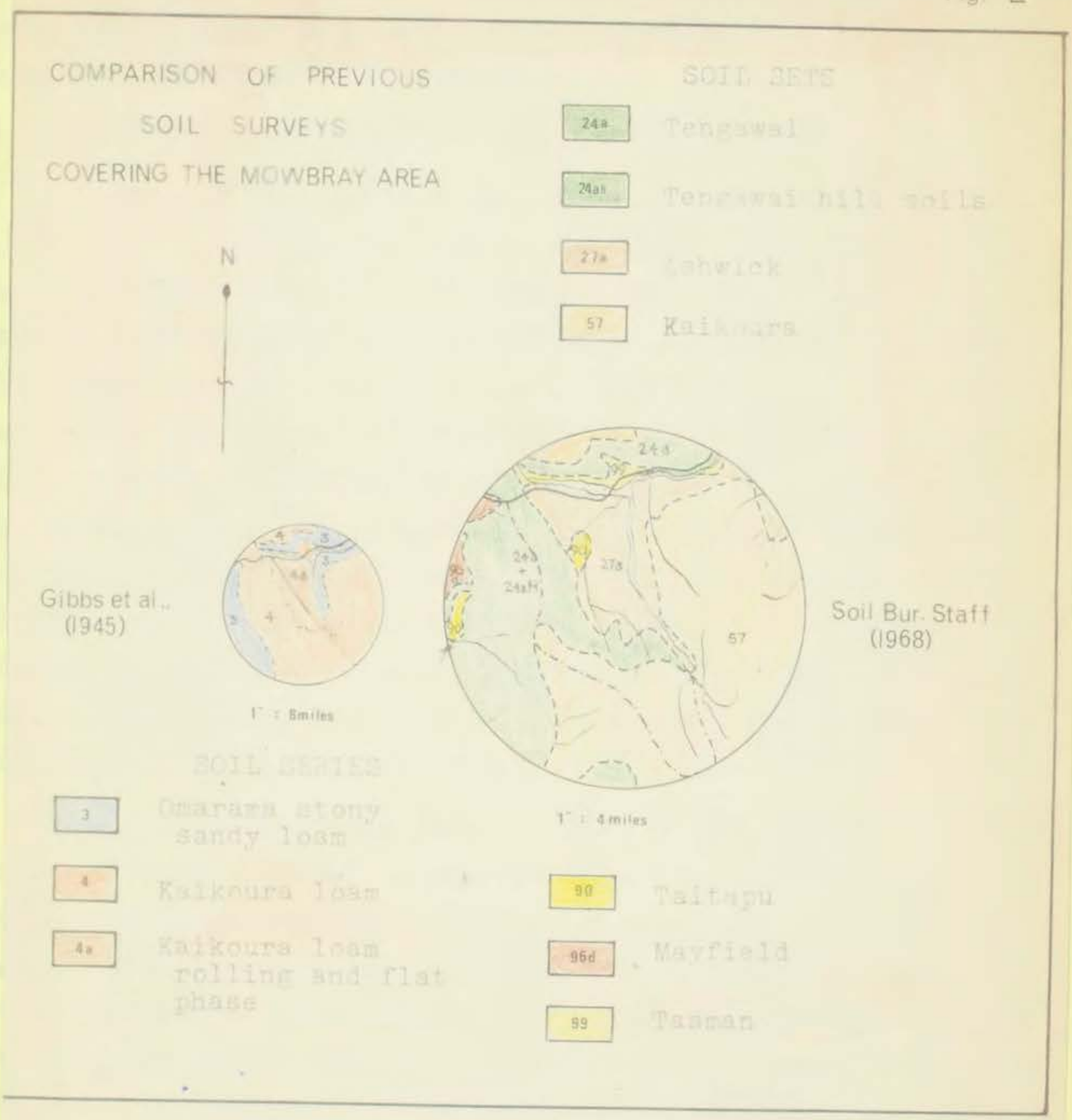
As a result, only that literature which is particularly relevant to the pedology and genesis of soils similar to those in the Mowbray area, and that which covers the basic survey techniques will be discussed. Particular emphasis is placed on New Zealand pedological conditions and conclusions. Overseas literature is only cited where it is felt necessary to illustrate techniques or studies which have restricted vogue in New Zealand.

2. PREVIOUS SURVEYS COVERING THE MOWBRAY CATCHMENT

The first recorded inventory of the soils of this region was carried out by Gibbs et al (1945). They mapped Kaikoura loams over the whole area with the rolling and flat phase of this soil covering the parts of the area of lower elevation. (Fig 2) Their maps were constructed at a scale of eight miles to the inch.

During the comprehensive investigation of the soil resources of the South Island (Soil Bureau Staff 1968a) the soils of the Mowbray area were again surveyed, and the subsequent maps at

Fig. 2


COMPARISON OF PREVIOUS
SOIL SURVEYS
COVERING THE MOWBRAY AREA
N
Gibbs et al., (1945)
1" : 8miles
Soil Bur. Staff (1968)
1" : 4miles
SOIL SETS
24a Tengawai
24aH Tengawai hill soils
27a Ashwick
57 Kaikoura
SOIL SERIES
3 Omarama stony sandy loam
4 Kaikoura loam
4a Kaikoura loam rolling and flat phase
90 Taitapu
96d Mayfield
99 Tasman

four miles to one inch showed Tengawai and Kaikoura soils on the hilly and steep lands and Ashwick and Tai Tapu soils on fans and terraces (Fig 2). An examination of the field sheet used during this survey (Soil Bureau Records) does little to elaborate on the quoted groupings.

3. PREVIOUS DETAILED SOIL SURVEYS IN NEW ZEALAND

Detailed surveys have been defined by Taylor and Pohlen (1962) as "... mostly for maps on the scale of 40 chains to an inch (1:31680), delineate soil types and land-use phases and show the soil pattern in relation to farm boundaries and sub-divisional fences". The Soil Survey Staff (1951) believe that soil types and phases should be mapped, on such surveys, in order to show all boundaries between mapping units, including areas of one unit within another. Soil types, and phases and variants of types are the mapping units employed on detailed soil maps, but both groups of authors agree that in some instances, due to the intricate pattern of soils, it is more appropriate to utilise well-defined soil complexes rather than vast numbers of individual taxonomic units of small areal extent.

The results of the first detailed soil surveys carried out in New Zealand appeared in pre-war times. The soils of the Heretaunga Plains (Hawkes Bay) were identified initially as soil series and were differentiated into types, phases and type variants based on parent material differences. The maps accompanying this report (D.S.I.R. 1939a) were produced at a scale of 30 chains to the inch. Waipa County (near Hamilton) was mapped in part pedologically at a scale of 40 chains to the inch and the soils were identified as series and differentiated on a type basis. Higher levels of classification were those proposed by Grange as outlined by Gibbs in N.Z. Society of Soil Science (1966).

Cutler et al (1957) carried out what was probably the first published detailed soil survey in the South Island. Their map, at 40 chains to the inch, showed 19 soil types, six phases of types and two soil complexes. By way of a table they attempted to show the genetic relationships between soil series. Cowie and Smith (1958) mapped several types and phases and also used a table to show the physiography/soils relationships, a rough approximation of soil genesis.

McCraw (1964) in text, as did Cutler et al and Cowie and Smith, discussed the soils of the Alexandra district on a physiographic basis. He mapped soil types and topographic phases of types. A short account attempted to elucidate the role of soluble salts in the formation of the soils of that area. Ward et al (1964) discussed soil types and drainage phases on a physiographic basis and attempted to show sequences of soil development by tabular presentation. Cowie and Hall (1965) and Cowie and Money (1965) mapped soil types and depth phases of types. The latter pair varied from the normal intext soil descriptions, and discussed soils according to the "common genetic classification" of Taylor (1948).

Both pedologic and physiographic groupings were used by McCraw (1966) in discussing the soils of the Ida Valley which were mapped in terms of types and topographic phases. Notes on the genesis of the soils were appended to this report. Fitzgerald (1966) separated phases on the basis of topography, salinity and drainage when discussing the physiographic groupings of soils of Heathcote County. Leamy and Saunders (1967) separated topographic and bouldery phases among their soil types which were grouped together physiographically. They included a chapter on soil genesis where they discussed soil formation in relation to the soil forming factors (Jenny, 1941) and polygenesis.

Cox et al (in press) went to some lengths to elucidate the genesis of the soils of Paparua County which were grouped on a physiographic basis. Phases of soil types were separated on the basis of depth of solum and morphological variations. The discussion on genesis revolved particularly around the events of the later Quarternary, the Aranuian stage of the Hawera series (Suggate, 1961, 1965; Suggate and West, 1967).

It would seem therefore, that detailed soil surveys should be carried out with three basic aims in view:

(a) soils should be mapped at the lowest practical level of interpretation, phases being used to subdivide soil types exhibiting variations over wide areas, and complexes should be employed where a more logical presentation of a complicated pattern is required;

(b) wherever possible notes on the genesis of the soils should be prepared, and arguments leading to genetic conclusions should be presented in order to logically explain the historical and morphological inter-relationships between soils; and

(c) finally, as detailed surveys are principally aimed towards the soil user, it is essential that a logical, easy to understand system of soil groupings is employed when discussing mapped soils.

In mapping the soils of the Mowbray catchment, soils have been shown as types and topographic, stony and eroded phases of types. Soil complexes have been shown on the map but their component parts have been indicated by symbols rather than assigning separate names as has been done by McCraw (1964), Cowie and Money (1965), Raeside et al (1966). Soils are arranged and extensively discussed on a physiographic basis. They have also been grouped pedologically and are in addition discussed according to the common genetic classification (Taylor, 1948) and technical genetic classification (Pohlen, 1962).

4. LITERATURE CONNECTED WITH THE MORPHOLOGY OR SOME ASPECT OF PEDOGENESIS OF HIGH COUNTRY SOILS

(a) Comprehensive soil surveys

Apart from the two broad soil surveys mentioned above (Gibbs et al, 1945 and Soil Bureau Staff, 1968a) very little investigation of the pedology of High Country Soils has been carried out. Gibbs and Beggs (1953), however, have mapped large areas of the High Country of Awatere, Kaikoura and Marlborough Counties on a reconnaissance basis.

On general soil maps of New Zealand (Taylor, 1948 and McLintock etc. 1959) high country soils have been delimited but very little has been said about their morphology, Soil Bureau Staff (1968b), however, have outlined the nature of soils similar to those found in the Mowbray area and brief notes on the genesis of soils are included. In addition, in that publication detailed chemistry, mineralogy and engineering characteristics are listed for two of the soils; the Puketeraki and Taitapu series; which are also found in the Mowbray area.

Vucetich (1968) in his broad outline of the soils of Canterbury has attempted to relate, on a developmental basis, the soils of various environmental zones. He has pointed out that the Puketeraki series are a common rolling terrain associate with the Kaikoura steep land soils in the sub-alpine zone of the province. Kirkliston soils are also found in this zone but are more characteristic of drier environments. At lower elevations but within the same sequence are the Tekoa steep land soils which may occur under beech forest or tussock grassland. The importance of erosion and drift in the formation of these soils is briefly discussed. Opuha and Kakahu series are considered to form the moister end of a climatic sequence of downland soils derived from loess and the occurrence of the Gley Recent Taitapu series on flood plains is outlined.

(b) Investigations into morphology and morphogenesis of soils similar to those found in the Mowbray catchment

Table 2 outlines the sources of information which discuss some aspect of those soils similar to the series found in the Mowbray area. Relevant discussion on previous investigations is included with the section on each soil later in this thesis. It is perhaps pertinent, however, to summarise briefly the nature and extent of these previous investigations.

Raeside and Baumgart (1947) discussed the extent of erosion of loess derived soils on the Geraldine Downs. The Opuha silt loam was considered to be one of a sequence of three soils occurring on these Downs and a typical profile was given. They came to no firm conclusion regarding susceptibility to erosion of the three soils investigated. They did, however, arrive at some fundamental observations connected with factors influencing sheet and wind erosion. Gibbs and Beggs (1953), as indicated above, mapped large areas of high country soils. They separated the Tasman, Tekoa and Kaikoura soils, noting the occurrence of one type within the Kaikoura loams.

Raeside et al (1959) and Kear et al (1967) gave representative profiles, from adjacent areas, of many types which also occur in the Mowbray catchment. Sherwood, Opuha, Tengawai, Wakanui, Skipton, Ashwick and Taitapu soils were described by either or both groups of authors. Kear et al did little to explain the influences of the soil forming processes in the formation of these soils. Raeside et al, however, in their earlier presentation, did note the importance of loess and erosion in the formation and differentiation of the soils on the Geraldine Downs.

Numerous other authors, Cox and Mead (1963), Fox et al (1964), Ward et al (1964), Fitzgerald (1966) discussed the morphology of soils similar to those occurring in the Mowbray area. Cox and Mead (1963) in particular contributed greatly to the understanding of the processes and sequences of soil formation on the lower Canterbury Plains and attempts have been made to relate their conclusions to soil forming events in the Mowbray catchment.

Barker (1955), Wraight (1963), Molloy (1964), and to a very limited extent Connor (1964) attempted to relate vegetation changes to present soils or palaeosols. Changes noted by Barker between short tussock and tall tussock grassland, and related to changes from Hurunui to Kaikoura soils are probably not as significant as she thought in the light of her own statement (p. 51) on the mobility of the boundary between the two grasslands. Recent work by Connor (1964) also casts doubts on the significance of such correlations. Due to the broad scale of mapping in the Wairau catchment (by Gibbs and Beggs, 1953) Wraight was unable to establish any correlation between vegetation and soils.

Molloy on the other hand, on the basis of charcoal examination, was able to show good correlation between the past vegetational history of the Porters Pass area and the distribution of Palaeosols. As a result of his investigations Molloy was able to establish a clear picture of the sequence of soil formation in the sub-alpine and alpine zones of his study area. He considered that the soils in the sub-alpine zone under Dracophyllum scrub and tall tussock grassland, and laterally under hard beech forest, were Tekoa steepland soils. Those under alpine tall-tussock and herbfield vegetation on leeward slopes at higher elevations were Kaikoura steep land soils.

Molloy was quick to point out the amount of modification to these soils caused by mass movement following Polynesian burnings and again in times of European occupation. McCraw (1962) also pointed out the significance of drift in the formation of soils on steep slopes, although he attributed the build-up of this material solely to climatic variations. Molloy (p. 159) also emphasised the importance of wind in the formation of soils, noted particularly by Raeside (1956 and 1964), even at high altitude on steep slopes.

The morphology and genesis of some soils similar to those found in the Mowbray area were discussed in a number of symposia organised by the New Zealand Society of Soil Science (compiled into Soil Groups of New Zealand 1966). The formation of yellow-grey earths in the South Island was outlined by Raeside, and Miller presented detailed chemistry of some yellow-grey earths including the Opuha silt loam. The significance of the soil forming factors in the formation of skeletal soils was discussed by Cutler. Vucetich wrote comprehensively on the morphological range and genesis of the Kaikoura steep land soils, and Blakemore presented analyses from two Kaikoura soils. Pullar discussed the formation of recent soils in this presentation, Cox recorded a profile of the Tasman sandy loam and Blakemore and Cox both outlined the chemistry of this series.

(c) Studies on particular aspects of the formation of high country and related soils

As early as 1932 the importance of climate as a differentiating factor in the classification of New Zealand soils was recognised. (Pohlen, 1962). It was not until Taylor (1948) established the early common genetic classification of New Zealand soils that the full significance of climate was appreciated as the principal factor differentiating the zonal soils of the country.

Hurst (1951) examined the climate at a number of yellow-grey earth and yellow-brown earth stations and attempted, on the basis of a number of climatic indices, to define the climatic conditions characterising these zones. She concluded in favour of Thornthwaites "rational" classification. More recently her work has been extended by Miller (in Soil Groups of N.Z.) and Cox (in Soil Bureau Staff, 1968b). Raeside (1948, 1956 and 1964), Cox and Mead (1963), Molloy (1964) have placed greater emphasis on the nature of past climates, considering that many soils in fact owe the greater part of the morphology to conditions which existed in the immediate past and which differ from those measured today.

Archer (1969) has attempted to show the influence of aspect in modifying the effects of climate and vegetation on the development of sub-alpine and alpine soils. Barker (1951) also appreciated the influence of aspect noting "... conditions at a given point on a southerly slope are equivalent to those at a higher elevation on an opposite northern slope". Sheltered aspects retain snow longer and have less evapotranspiration, due to a shorter period of exposure to direct insolation, than equivalent exposed slopes, but are also sheltered from the dessicating effects of the northwest wind. Due to such temperature differences, and despite the higher moisture conditions on sheltered aspects, the high country soils on these aspects are not usually weathered to the same extent as the deeper (only slightly eroded) soils on exposed aspects at the same level. Erosion, mass movement, preferential grazing (and burning) are all factors, however, which tend to complicate this pattern. Archer (pers comm) has also considered the effects of annual snow cover and the development of soils which have recently been freed of permanent snow and ice. In the light of recent work by Stepanov (1962) such studies will help to illuminate processes operative in the early stages of formation of high country soils at the end of the glacial period, and in areas which have recently been exposed to weathering and leaching following the retreat of permanent snow and ice.

Taylor in proposing his genetic classification of soils placed great emphasis on the processes of soil formation, which he grouped under the headings: A. Soil Wasting; B. The Organic Cycle, and C. The Inorganic Cycle. There seems to be a shortage of comprehensive work on the integrated effects of all soil forming processes but various aspects, with particular reference to high country and related soils, have been investigated in detail.

Extensive studies on the biology of tussock grassland soils have been carried out over a number of years. This subject is outside the scope of this thesis but it is of significance to note that one of the soils studied was the Tekoa steep land soil (Thornton, 1958). In discussing the problems associated with the regeneration of the snow-tussock grassland the Tussock Grassland Research Committee (1954) established in some detail the physical nature of the Kaikoura soils. The effects of frost and subsequent erosion in relation to surface expression, texture, structure and soil stability were particularly discussed.

As a follow-up to these investigations, Gradwell (1954, 1955 and 1960) studied the effects of frost on the soils of depleted snow-tussock communities. Gradwell (1962) and McDonald (1961) examined the physical properties of high country soils derived from greywacke rock (including the Kaikoura steep land soils). Their results are significant for research into the re-establishment of grasslands on eroded hillsides in the high country and also serve as a basis for characterising erodibility of soils in terms of soil physical properties.

Soil erosion studies, particularly on high country soils were undertaken by Gibbs et al (1945). More detailed studies, such as that of Hayward (1969) are required to accurately assess the rate of loss of soil from the high country and the mechanisms of erosion in relation to soil characteristics. Detailed work on erosion of the downlands, Gibbs (1945), Raeside and Baumgart (1947) and Packard and Raeside (1952) has indicated that erosion can also be a problem on deeper soils of drier environments. Such studies have also helped to accentuate the importance of wind erosion. Soons (1968) has recorded the importance of frost in the preparation of surface soils for erosion by wind in the high country. She also believes that surface runoff is a principal agent of erosion on the loess covered downlands.

The problem of instability in New Zealand steepland soils has been outlined by Gibbs (1962). Cutler (1962) on the other hand noted that in many areas stability exists among steep land soils but accepted that large acreages of such soils were inherently unstable. His belief that greater investigations into the soil-plant-animal problem could provide bases for overcoming the instability problem has been pursued, in part, in this project. McCraw (1959, 1965, 1968) in accepting the problem of instability has contributed greatly to the understanding of the processes causing instability and the soils landscapes resulting from such instability. Cutler (1955) considered the problem of instability on soils derived from loess in a different light, noting distinct differences between soils where loess was accumulating and regions of non-accumulation, and suggested that soils where rates of accumulation and depletion are equal would be the most mature soils in any landscape.

In his studies using sweet vernal to assess the availability of elements in a range of New Zealand soils, Wells (1956a, b) and Wells and Saunders (1960) included the profile from the Opuha soils and two Kaikoura profiles in the study. These are particularly important in providing data on the phosphorus status of these soils which can be compared with the results obtained from the phosphorus fractionation of similar soils from the Mowbray area. McFadden (1969) has recorded information on the response of clover to phosphate application on Tasman and Kakahu soils from the upper Rangitata area, and this also provides useful comparisons with the similar soils in the Mowbray catchment.

5. RECENT ADVANCES IN CHEMICAL AND MINERALOGICAL ASPECTS OF SOIL FORMATION IN NEW ZEALAND

(a) Chemistry and soil formation

The general nature of the chemistry of the soil groups of

New Zealand (according to the common genetic classification of Taylor, 1948) and the detailed chemistry of Soil Bureau reference sites have been discussed by the Soil Bureau Staff (1968b). Determinative methods employed have been detailed by Metson (1960, 1961). Of significance during the present study are the results of Metson and Blakemore (in Soil Survey Staff, 1968b) who indicate that the yellow-grey earths have medium CEC usually rising in the B horizon, which has the highest levels of expanding micaceous clays in the profile. Base saturations of these soils do not decrease down the profile as markedly as those of yellow-brown earths. Rising exchangeable Mg and Na down the profile has been noted as a pallic (yellow-grey) characteristic which is, however, not a feature of shallow and stony soils related to yellow-grey earths. They also consider that the low levels of exchangeable bases in the lower horizons of high country yellow brown earths is indicative of greater leaching in these soils and note that in some cases rising CEC in subsoils of this group is due to clay illuviation.

Metson, in that publication, has also noted that a decrease in exchangeable potassium with increasing depth is particularly marked in the weakly weathered but strongly leached soils (which includes the high country yellow-brown earths), but soils with a pronounced fragipan or "claypan" sometimes show an increased exchangeable-K value in the deeper subsoils.

Saunders (in the same volume) recorded that the total phosphorus values of the solum of weakly weathered zonal soils tended to be higher than those of their parent rocks. A similar conclusion was reached by Walker and Adams (1959) who concluded that phosphorus had been lost from the moderately and strongly weathered profiles but not from the weakly weathered profiles.

Saunders also noted that the solum total - P value of the hygrous yellow-grey earths was lower than that of the (drier) sub-hygrous yellow-grey earths. The difference being due to the very much lower P values of the B horizons of the hygrous profiles, probably resulting from a greater degree of enleaching. This abrupt decrease of total - P values from the A to B horizons was also considered to be a feature of the intergrade soils. However, amongst the high country yellow-brown earths the P content of the B horizons was often greater than that of the A horizons.

Saunders noted that the ignition method (where the organic P is assumed to be the increase in acid-soluble phosphorus after the ignition of the soil) compared favourably with the alkaline extraction of organic phosphorus. Values for organic - P determined by the ignition method generally followed the same trends as the total solum - P values.

Wells and Saunders (1960) determined the amount of inorganic P in topsoils soluble in N. H_2SO_4 and found on a single parent material the P soluble in N.H_2SO_4 decreased with increasing degree of weathering. Saunders noted a similar trend for values of acid soluble P in the solum. The overall decrease being atributed to a compromise between a decrease in total amount of inorganic P and a decrease in its solubility in N.H_2SO_4.

As a result of investigations into the fractionation of soil phosphorus in New Zealand Walker and Adams (1958, 1959), Walker (1962, 1965), Stevens (1963), Williams (1965), Syers (1966) and Shah et al (1968) and overseas (reviewed by Williams, 1965), it was shown that transformations in phosphorus fractions in soils can be directly related to pedogenesis. The transformations occurring can be grouped according to the equation (Walker, 1965):

$$Pt = Pa + Po + Pf$$

where Pt = total -P extracted by Na_2CO_3 fusion and Hcl digestion

Pa = inorganic -P soluble in $N.H_2SO_4$

Po = organic P determined by ignition and digestion in $N.H_2SO_4$ minus Pa

Pf = considered to be occluded -P and determined by subtraction Pt - (Pa + Po).

The relationship of these fractions to those determined by more detailed fractionation procedures has been shown by Williams (1965) and Shah et al (1968). However, there is no certainty as to the precise forms of phosphorus present as Pa. Shah et al (1968) have shown that Pa can be approximately equated with the sum of calcium bound - P (Ca - P), and the non-occluded P (surface bound forms of Al -P and Fe-P), noting, however, that soil development has a marked effect on this relationship. In particular, for moderately and strongly weathered soils,

$$Pa < Ca\text{-}P^{\#} + \text{non-occluded } P$$

whereas for weakly weathered soils Pa will include both Ca-P and non-occluded P and even some of the occluded P.

Work by Saunders (1965) on phosphate retention, by Blakemore (1969) on the relationship between Tamms extractable iron and aluminium and by Claridge (1962) on extractable iron, all have distinct pedogenic conotation, but as these methods have not been applied during this study it is only considered relevant to mention their work in passing.

(b) <u>Mineralogy and soil formation</u>

Determinative methods in clay mineralogy have been applied

Ca-P does not include calcium bound phosphorus such as apatite which is included within the crystals of other minerals.

to New Zealand soils over the last decade and a half by Fieldes and Swindale (1954), Fieldes and Williamson (1955), Fieldes (1955), Fieldes et al (1956), Fieldes (1957), Furkert and Fieldes (1968) and Claridge (1969). The results of these investigations have been correlated with the common genetic classification by Fieldes and Taylor (1961) and the emerging sequences of weathering and clay mineral genesis have been outlined by Fieldes (1962, 1968) and in Soil Bureau Staff (1968b), and by Furkert and Fieldes (1968) and Birrell and Fieldes in Soil Bureau Staff (1968b).

The dominant crystalline clay minerals in the following New Zealand soils have been summarised in Soil Bureau Staff (1968b) as:

yellow-grey earths - mainly illite with different amounts of clay -vermiculites, montmorillonites and interlayered hydrous micas.

yellow-grey earth to yellow-brown earth intergrades - intermediate between above and below.

high country yellow-brown earths (weakly weathered) - clay vermiculites and/or illite dominant with some montmorillonite and interlayered hydrous micas.

The mineralogy of the sand fraction of New Zealand soils is less well known (Fieldes and Weatherhead 1966 and in Soil Bureau Staff, 1968b), but it is considered that correlations demonstrated in these papers show that a relationship does exist between sand mineralogy, soil processes and clay mineralogy. Swindale (1966) concluded similarly in his comprehensive study of the mineralogy of soil derived from basic and ultra-basic rocks.

Very little work, however, has been done to show the relationship (if any exists) between the clay mineralogy of the developing soils and the underlying parent material. Swindale and Hughes (1968) have shown that clay minerals, not normally encountered in a particular zone may occur in soil parent materials and recent work by the author has indicated that such minerals may persist in the solum (confirmed by Wells and Blakemore - pers comm) indicating a stage of weathering in advance of that expected for the zone. With the increasing tendency to examine whole soils (Furkert, 1969 and Campbell pers comm), with a minimum of pre-treatment, it will be both logical and easy to extend observations into the parent material and underlying horizons. Such studies will help in elucidating the extent to which pedogenesis is operating in the present cycle.

The occurrence of metahalloysite and gibbsite in soils in the Mowbray area could be indicative of advanced stages of weathering. Fieldes (pers comm), however, has indicated that these minerals appear in many yellow-grey and yellow-brown earths (although not mentioned in previous publications) and are probably residual either from previous more advanced cycles of weathering or are derived directly from an occurrence in the parent rock/material.

6. SOIL CLASSIFICATION IN NEW ZEALAND

Gibbs (1965) gave a schematic outline of the history of soil classification in New Zealand in the form of a dendrogram. He also discussed each of the soil groups according to the common genetic classification of Taylor (1948), with amendments proposed in McLintock (ed. 1959), in light of their broad environmental characteristics. He gave their nomenclature according to the technical genetic classification (Pohlen, 1962) and noted previous names for the groups and their overseas correlations.

Pohlen (1962) summarised the history of soil classification leading up to the emergence of the technical genetic classification (Pohlen 1962 and Taylor and Pohlen 1962). The amendments to the common genetic classification of Taylor (1948); which focussed attention and investigation on the processes of soil formation; were the application of regional names - High Country, Southern and Central, and Northern for the weakly, moderately, and strongly weathered yellow-brown earths and the replacement of skeletal soils with the term steepland soils (McLintock, ed. 1959).

The aim of the technical genetic classification was to give precise technical definition to the common names of the earlier classification, and to draw attention to the importance of the effects of the soil forming processes in soil genesis. In this grouping the object of classification was the net result of the interplay of the existing (and past) environmental influences on the soil body.

The categorical bases of this classification were:

I - basal form of the soil body (i.e. general appearance),

II - the main energy status as indicated by latitudinal and altitudinal zonation and soil moisture status,

III - the kind and grade of argillisation (i.e. degree of weathering experienced by the soil body and the nature of the clays so formed), or the processes of accumulation, removal and mixing which tend to modify weathering,

- and at lower levels, on the nature, extent and intensity of the processes which modify the soils in the above categories.

This classification allowed greater definity of soil grouping and nomenclature than had existed previously. The nomenclature gave a direct insight into soil genesis and soils formed as a result of similar processes could be easily identified. An easing of the bias towards sharply delimited zones also resulted. The groupings, however, did presuppose a knowledge of the dominant clay minerals present, levels of exchangeable bases and an accurate assessment of the mechanical constitution. Similarly, poor definition of sub-units of intensity within some of the lower categories leads to confusion of application, especially amongst workers of limited widespread experience (e.g. a pedologist working in a small local area may consider that his soils showing the maximum iron illuviation are strongly iron illuvial, whereas on a national basis they may be only moderately or even weakly illuviated). The fact that this classification was designed to be used in conjunction with, rather than replace, the common genetic classification has also led to cofusion among many working in fields related to pedology.

Fieldes (1964, 1968) and Fieldes et al (1965) attempted to go beyond this classification by proposing a series of groupings determined by the nature of the dominant clay constituent. This constitutional classification, although designed to be used in conjunction with the technical genetic classification appears to have been used as a separate grouping. This is most probably because the major classes often cut across boundaries between the major groups of the previous classifications. It does presuppose a knowledge of the dominant clay minerals but is as yet still in the stage of infancy and as such is difficult to criticise. A more detailed account of the application of this grouping , its limitations and advantages will be given later.

7. SURVEY TECHNIQUES AND SOIL MAPPING

The essential elements of soil surveys are the identification and characterisation of soil taxonomic units, the areal delimitation of these taxonomic units and the grouping of taxonomic units into mapping units which themselves are dependent on the scale, nature and purpose of the survey. The description and identification of soil profile characteristics has been well documented in the past in manuals such as those produced by the Soil Survey Staff (1951), Clarke (1957), Taylor and Pohlen (1962), Leamy and Panton (1966) and in more specialised articles such as Whiteside (1959), USDA (1960), Gile et al (1965). Methods for the delimitation of taxonomic and/or mapping units, however, have not been as rigidly defined.

(a) Soil survey techniques

The Soil Survey Manual (Soil Survey Staff, 1951) discussed the use of the plane table, and pace and compass surveys in mapping. Taylor and Pohlen (1962) mentioned the conduct of soil surveys but said little about the actual techniques involved in the location and extrapolation of soil boundaries. Leamy and Panton (1966) covered in some detail the essential elements of chain and compass traverses in forested country. Barrera (1961) was remarkably vague, leaning heavily on the methods outlined by the Soil Survey Staff (1951).

In fact it would seem from the literature that the techniques to be applied in the conduct of a soil survey are a matter of individual decision. These may vary from intersection or radial plane table location, to chain or pace and compass traverses, to free traversing in regions where sites can be located easily by grid reference or by offset from easily identifiable features.

(b) The use of aerial photographs

Since the mid 1930s soil surveying in the United States has been based on aerial photographs (USDA 1966). Aerial photographs and aerial mosaics have also been used extensively in this country in more recent times in place of base maps (Gibbs, pers comm). Aerial photographs have been used extensively overseas as preliminary guides in the planning and demarcation of broad boundaries prior to the commencement of surveys (Barrera, 1961; Thomas, 1962; Cabrita, 1963; Leamy and Panton, 1966; Andronikov, 1967) and have also been used directly in the production of reconnaissance and detailed soil maps (Gunn, 1955; Simakova, 1964, 1967; Hooper and Ives, 1965; USDA, 1966; Tolchel'nikov, 1967).

Methods for the interpretation of photographic aspects of natural and cultural features in terms of soils and soil characteristics have been outlined by Simakova (1964), USDA (1966) and Rikjse (1966). In addition Simakova (1964) has detailed the use of colour aerial photography in soil mapping in the Caspian lowland and Avery (1968) has discussed the application of remote sensing techniques, based on aerial observation, to the interpretation of soil data.

Obvious disadvantages of air photos, however, are the ever present scale distortion in areas of broken country, the image distortion away from the photo centres and the obscuration afforded by cultural activities. Consequently, there has been a marked tendency towards the use of controlled mosaics which are prepared at a definite scale and adjusted so that distortion is at a minimum.

In areas of little relief variation, mosaics can, and have (Soil Survey Staff, 1951; Gibbs, pers comm) been used as field sheets enabling the user to obtain a high degree of accuracy. A major limitation though is their inability to show the terrain contrasts in areas of broken relief that are visible on stereoscopic examination of stereo pairs. Thus air photos must remain a fundamental tool for survey work in areas of broken relief and mapping techniques must be such that scale and image distortions are corrected.

Plotting soil boundaries onto air photos by photo-analysis techniques following initial ground control enables the surveyor to move randomly about the area locating observations by reference to easily identifiable features (Soil Survey Staff, 1951) thus eliminating much of the drudgery of routine examination along a series of pre-arranged traverse lines, or of following-out boundaries in the field (Soil Survey Staff, 1951 p. 440; Taylor and Pohlen, 1962 p. 146). Similarly, boundaries based on initial observation direct the surveyor to areas which require more detailed observations and indicate those areas where only a minimum number of observations are required.

(c) <u>The preparation of field sheets</u>

As noted above, there is an increasing tendency to use aerial mosaics as field sheets, marking symbols for taxonomic units as one proceeds (Soil Survey Staff, 1951; Gibbs, pers comm). Taylor and Pohlen (1962) are particularly vague, however, in discussing the construction of field sheets and base maps, but Leamy and Panton (1966) have on the other hand gone into some detail to explain the construction of field sheets/base maps from comprehensive traverse notes. The use of large scale air photos, enlargements of same or photo-mosaics, however, precludes the necessity of making comprehensive traverse notes, particularly in respect of soil boundary changes. Such boundaries can be marked on photos before commencing comprehensive traversing thus enabling soils to be identified directly onto the photo by a series of symbols, supplemented by ancillary notes of site and profile characteristics.

(d) Soil mapping units

In the initial construction of field sheets, soil taxonomic units are identified. On detailed surveys these are soil types, phases and variants. In the preparation of maps from detailed soil surveys most, but not all, of the taxonomic units are mapping units (Soil Survey Staff, 1951). These are most frequently at the type and phase level (Taylor and Pohlen, 1962). However, as pointed out by Johnson (1962), the kinds of map entities selected, the map scale, and the level of cartographic detail must be adjusted to the major objectives of the survey and to the complexity of the soil pattern.

Consequently in conducting his survey and producing a soil map the surveyor must take cognizance of the requirements of the survey and the needs of the map user. A map of great detail may be too confusing for the user, yet one which has been over-simplified may not contain sufficient information. The soil surveyor then, has the task of presenting his taxonomic units in terms of mapping units in such a manner that the user of his map is supplied with all the information required, yet is not confused with detail.

In the survey of the Mowbray catchment it was considered that the primary aim was to produce a map highlighting the complexity of soils on hilly and steep slopes in the high country, yet capable of showing that inter-relationships between soils could be easily interpreted in terms of the soil forming processes. To achieve this, phase differences in some areas have been elevated to type or sub-type status, or have been indicated by the use of symbols, and soil complexes have been mapped in the colour of their major component with the presence of their various constituents indicated by symbols.

CHAPTER III

METHODS

1. TECHNIQUES IN COMPILATION OF DATA

(1) Preliminary Investigations

Prior to commencing the major part of the survey of the soils of the Mowbray area preliminary investigations were carried out to gain an idea of:

(i) the distribution of land forms,

(ii) accessibility of various areas,

(iii) the possible extent of soils likely to be encountered,

(iv) and to enable a plan of survey to be drawn up;

in order to achieve this the following techniques were employed:

(a) Aerial reconnaissance - A reconnaissance in a light aircraft both at high and low altitude was carried out over the valley. On the first flight this achieved little more than a familiarisation with the distribution and nature of terrain and vegetation. On a later flight, which followed an extensive period of field investigation, it was possible to observe soil/terrain unit changes and follow them laterally away from their noted occurrence on traverse lines.

Unfortunately, due to the relatively high ground speed of the aircraft, it was not possible to mark boundaries directly onto the map, but this is a principle which could be investigated for use with slower moving aircraft such as helicopters.

(b) Air-photo analysis - Although soils do not appear on air-photos as such, except where vegetation cover is sparse, changes in the nature of soils can be inferred from changes in elements with which soils are intimately related. In particular, changes in terrain, vegetation and the hydrologic character of a landscape. In addition, cultural practices often indicate major (and minor) soil changes.

Air-photos have been used extensively in soil mapping at a variety of scales (Avery, 1968), (Simakova, 1964) and over a wide range of environments from the sub-artic regions (Tolchel'nikov, 1968; Simakova, 1968) through sub-tropical forests (Cabrita, 1963) to the dry (Gunn, 1955) and moist (Hooper and Ives, 1964) tropics. Basic principles of interpretation, with particular reference to soils have been outlined by Simakova (1964), the USDA (1966) and recently in New Zealand by Rijkse (1966).

In carrying out an air-photo analysis there are three basic steps to be considered:

(a) identify as wide a range of individual characteristics as possible,

(b) determine which characteristics are commonly associated and hence,

(c) delimit the units so emerging, noting the range of observed photo characteristics within each. (Adapted from Cabrita, 1963).

The writer has established units on a two criteria basis:

(i) <u>the nature of the land surface</u> - which includes:

- (a) part of overall geomorphic landform,
- (b) terrain - e.g. slope, length of slope,
- (c) position on slope;

(ii) <u>the air photo aspect</u> of the unit - which includes:

- (a) size of whole or individual parts,

(b) shape of whole or individual parts,

(c) shade or tone which may vary from white through various greys to black,

(d) pattern indicated,

(e) relationships with adjacent units.

On this basis an analysis of the air-photos covering the Mowbray area at a scale of one inch to fifty chains was carried out.

(i) Nature of the land surface -

(a) geomorphic units:

(1) flood plains

(2) terraces - according to level (height) 1, 2, etc.

(3) low angle fans - 5° slope,

(4) low fans - 5° - 12° slope,

(5) high angle fans - 12° + slope,

(b) terrain units:

(1) moderately sloping hillsides,

(2) strongly sloping hillsides,

(3) steeply sloping hillsides,

(4) very steeply sloping hillsides.

(c) position and shape of slope:

(1) lower or foot-slope,

(2) central or mid-slope

(3) upper-slope,

(4) ridge crests,

(5) uniform slope,

(6) convex slope,

(7) concave slope.

(ii) The air photo aspects as revealed by the nature of the vegetation and the degree of cover exhibited by the vegetation.

Using the shape, size, tone and patterns within units, the following subdivisions were established:

(a) drainage characteristics:

(1) well drained,

(2) imperfectly drained,

(3) poorly drained.

(b) surface stoniness characteristics (largely dependent upon initial extensive ground investigation):

(1) non stony,

(2) slightly stony - scattered stones 30'-100' apart,

(3) stony - common stones 5'-30' apart,

(4) very stony - many stones 2½'-5' apart,

(5) extremely stony - almost continuous coating of stones.

(c) erosion characteristics, where possible determined from evidence indicating:

(1) wind erosion - either subject to deflation or accumulative sties,

(2) sheet and rill erosion,

(3) gullying,

(4) screes.

Each characteristic was indicated by a number or a letter and then units were delimited on the air-photos on the basis of recurrence of the same letters and numbers in combination. A tentative grouping was then established primarily on the basis of location, e.g.

(1) on hilly and steep lands,

(2) on, or adjacent to the Mowbray fan,

(3) on, or adjacent to the Orari fan,

(4) on, or adjacent to the Meikleburn fan and floodplain.

The next step was to carry out a rapid traverse over selected routes to correlate the air-photo units with field occurrences.

(c) <u>Rapid traverses</u> - Three rapid traverses were carried out in an attempt to correlate the established air-photo units with actual soils units in the field. One traverse covered the lower part of the Mowbray fan, the Meikleburn floodplain and the lower part of the Orari fan and adjacent hillsides. A second traverse covered the upper Mowbray fan and adjacent northern portion of Lucas's Hill. The third traverse crossed the Meikleburn fan, upper Meikleburn, upper Mowbray and the Mowbray gorge.

As a result of complete (detailed) and partial profile descriptions obtained during these traverses a tentative legend based on:

increasing subdivision

1. parent material)	Site characteristics
a. terrain)	
(1) depth of solum and degree of development)	Soil characteristics
(a) drainage)	
(i) profile morphology)	

was established.

2. <u>Establishment of the Tentative Legend</u>

Following air-photo analysis and rapid traverses it was possible to develop a tentative legend, classifying the physiographic/pedomorphic units of the Mowbray area. Although previous surveys had indicated the range of soils likely to be encountered in the region, it was decided, because of initial difficulty of

Table 1 - Tentative Legend - Soils of the Mowbray Area

Parent Material	Terrain/Landform	Soil Depth/Horizon Development	Drainage	Pans - or distinct horizons	Other Features	Horizonation	Final Correlation
A* Soils on Alluvium (and some wind-borne fines)	Floodplains, terraces and low-level fans	1. Immature)	a. well drained			AC	Tasman
		2. Weakly developed)	b. imperfectly drained			A,AB/BC	Ashwick
		3. Moderately developed)		i. non compact subsoil		A (B) C	Mowbray
						A B C	Meikleburn
		4. Moderately-strongly developed	a. well drained	ii.compact subsoil		ABC	Sherwood
			b. poorly drained	i. weak gley		A Bg C	Wakanui
				ii.strong gley		A (G) C	Taitapu
B Soils on Deep Loess Deposits	Rolling and hilly surfaces		3. poorly drained	strong gley		A G C	Clayton
			1. moderately well drained	compact subsoil	a.weakly developed B horizon	A B C	Opuha
					b. moderately dev. B horizon		
					i. dark brown A_1	A B C	Sherwood (hill
					ii. dark grey A_1	A B C	Skipton
C Soils on Loess Over Mixed Loess and Colluvial Debris	1. Rolling hillsides		a. well drained			A B C	Kakahu
			c. poorly drained			A Bg C	Clayton (hill)
	2. Hilly surfaces		a. well drained	(incls assoc. stony soils)		A B C	Kakahu (hill)
			b. imperfectly drained			A B C	Opuha (hill)
D Soils on Mixed Loess and Colluvium	1. (Hilly lands	Moderately deep					
	((Steep lands **	Shallow					
	2.(Very steep lands	Shallow			a. 3000' asl	A(B)C	Puketeraki
					b. 3000' asl	A(B)C	Lookout
E Soils on Predominantly Colluvium Debris	1. Strongly sloping fans	Shallow				AC	Tengawai
	2. Steeply sloping hillsides	Shallow			a. 3000' asl	AC	Kaikoura
					b. 3000' asl	AC	Tekoa
F Sedentary Soils on Parent Rock in Place	1. Rolling - hilly ridge crests	a. Shallow				A,AB/BC	Kaikoura (hill)
		b. Moderately deep				A B C	Kirkliston

* Letters/numbers used as identifying symbols during mapping

** Steep and very steep in this sense mean strongly-steeply sloping and steeply sloping (Taylor and Pohlen 1962).

correlating the observed soils with previously recorded types, to use a notation system based on observable characteristics.

The nature of the Parent Material Classes and the Terrain were chosen as the prime measureable functions of the classification. Subordinate to this were depth of solum, drainage and profile morphology. Because of limited data on rainfall (and climate) and distribution of vegetation, these two criteria were only used in conjunction with other measureable factors such as aspect and exposure. The tentative legend (Table 1) was drawn up following initial rapid traverses and was correlated directly with the air-photo analysis, initial notations marked on photos following the photo-analysis were then replaced with the notation of the tentative legend.

One was then in a position to investigate the various predesignated units in the field and note the existence of similarities or differences within and between units, thus verifying the reliability of the air-photo analysis. At the same time extensive soil information was obtained which enabled correlations to be made between the soil units as designated and existing recorded soil types.

3. Field Investigations

Field investigations of the soils of the Mowbray catchment have been carried out with three basic aims in view:

(i) to map the soil pattern in detail after preliminary identification with the aid of air-photos,

(ii) to determine the relationship between soil units located during (i) above, and

(iii) to determine the variation within homogeneous mapping#1 units and the amount and extent of inclusions within heterogeneous#2 units.

A variety of techniques were employed in order to fulfill these aims.

(a) Comprehensive traverses - These were foot traverses along either preselected routes or along and across obvious topographical features such as fences, tracks, obvious ridges etc. The route was located on the air-photos and transferred to an air-photo enlargement. Relevant information obtained along the traverse, from offsets or from binocular observation of adjacent areas was initially recorded in a field book and was later placed on the photo enlargement by estimation.

Soil boundaries so located were found to conform fairly closely with those plotted initially on the air-photos following photo-analysis. In some cases, particularly in steep country, boundaries were sketched directly onto the air-photos in the field as initial interpretation had not been definitive enough to locate the boundaries precisely. This was particularly so in the case of the high country yellow-brown earths.

#1 homogeneous mapping units - the soil type as defined by Taylor and Pohlen (1962) is considered to be a homogeneous or near homogeneous segment of the soil landscape and may contain 10-15% of other soils as inclusions.

2 heterogeneous units - are those mapping units containing an intimate mixture of two or more homogeneous units which cannot be separated, or it being impractical to separate at the scale of mapping - such units are the soil complex and the soil association (Taylor and Pohlen 1962).

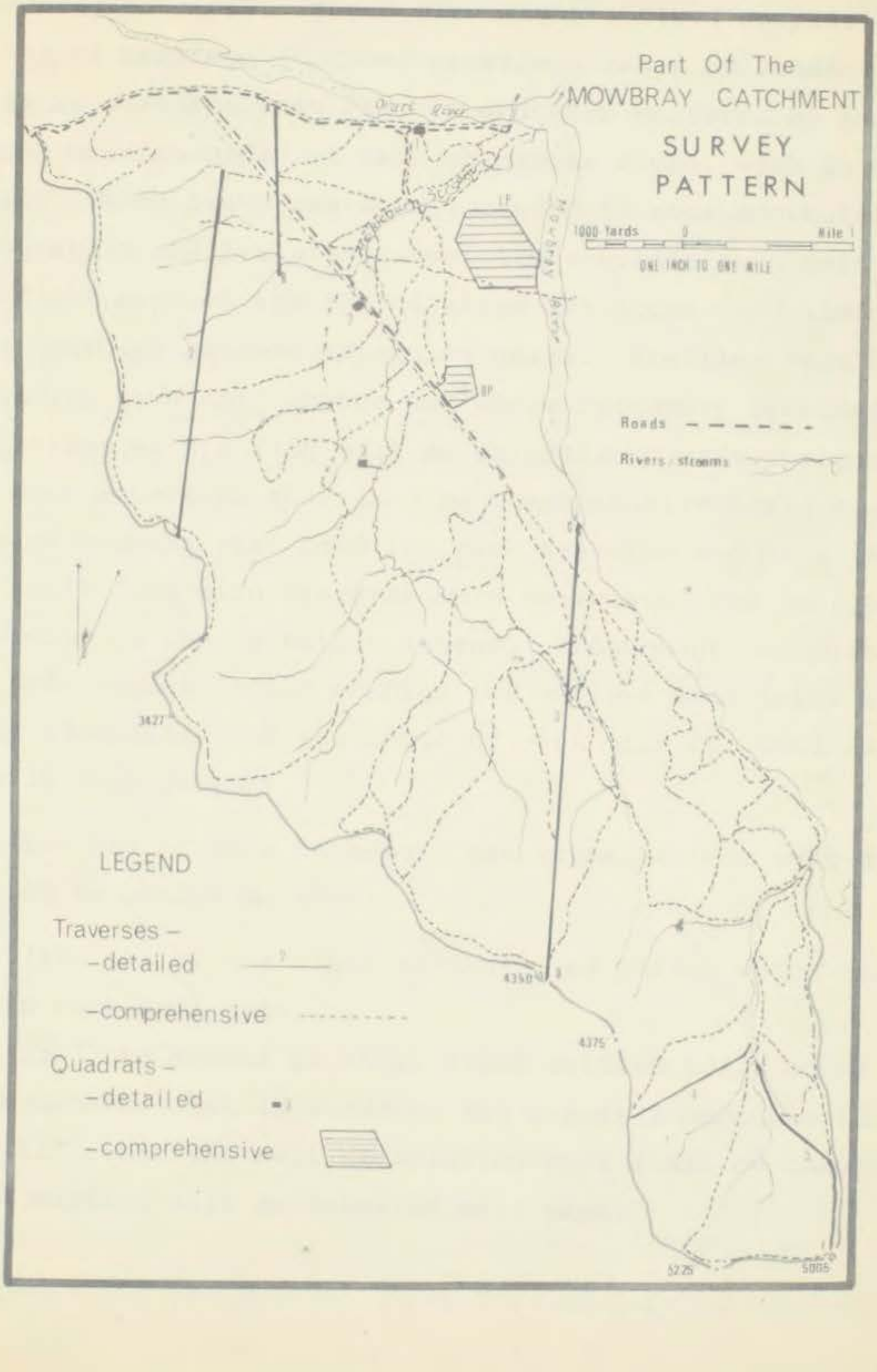
Extrapolation of boundaries between traverses was then made by air-photo analysis. Extra traverses were then planned to cross some of the interpolated boundaries in order to check the validity of the air-photo interpretation.

Each new soil on each traverse was assigned a number. Soil numbers were then correlated with each other and with the tentative legend. The aim was maximum objectivity in order to produce groups of like morphology and genesis.

Because of the complex pattern of soils on the low-level fans of the Mowbray and Orari it was necessary to interpret the preliminary analysis of photo data in these areas after completing the traverses. However, because of the lack of good definition on air-photos and the complex pattern of closely related types and phases of the soils on these surfaces, it was not possible to delineate all the soils by air-photo interpretation (see plates 1, 2, 16, 17 and 18). It was decided therefore, to map these soils as broad soil associations. (Taylor and Pohlen, 1962) On the rolling, hilly and steeplands preliminary boundaries from air-photo interpretation were found to conform closely to changes observed in the field by comprehensive traverses. It then became a matter of grouping the small range of soils, within each tentative legend unit, into a particular soil type or number of types.

Such a technique obviously emphasises the surficial form of soils. This tended to establish a set of predefined groupings based on the nature of surface deposits and the processes of the drift regime, the nature of the terrain units and the degree of continuity of vegetative cover. As a consequence, true objectivity in assessing the morphological and genetical relationships of various soils has not been completely maintained, but the system appears to have worked sufficiently to allow accurate

Fig. 3


Part Of The
MOWBRAY CATCHMENT
SURVEY
PATTERN
1000 Yards
0
Mile 1
ONE INCH TO ONE MILE
Mowbray River
Roads
Rivers/streams
3427
4350
4375
5225
5005
LEGEND
Traverses –
-detailed
-comprehensive
Quadrats –
-detailed
-comprehensive

correlations with established soil types from adjacent areas.

(b) Detailed traverses - Five traverses were carried out in much greater detail than the comprehensive traverses along pre-selected lines. These were along a fixed compass bearing or series of bearings to cover as wide a range of landforms and soils as possible (see Fig. 3) and were measured by pacing. Slopes were recorded at each change in slope, with an abney hand level. These traverses were intended to show accurately the topographic and lithologic variations within each unit shown on the field maps at the end of stage (a) above, and also the relationships between adjoining units. Profiles were examined following each soil change and where necessary recorded in full. Variations within each soil so established were designated in the same manner as that used on comprehensive traverses. Different sets of numbers were used for each traverse and at a later date the soils from each traverse were correlated and designated according to the tentative legend. Subsequent correlation with the pedological legend enabled the various soil types and phases to be identified and the range of each unit ascertained (see plan in rear pocket).

The use of this technique has revealed that even detailed mapping is unable to show:

(i) all of the minor variants and phases which exist within each soil type,

(ii) the amount to which other related soils occur within the bounds of what is shown on the map as a homogeneous unit, and

(iii) that the soil association must still be considered as a valid mapping unit on detailed soil maps.

(c) <u>Comprehensive quadrats</u> - In order to obtain a more realistic picture of the relationships between various soils on the fans than was apparent from line traverses, two broad quadrants encompassing whole paddocks were examined in fine detail.

Soil boundaries were located by pacing along the peripheral boundaries of paddocks and along selected traverses across the paddocks. The paddocks as outlined by their fence pattern on the 20 chain map enlargements were then enlarged to a suitable scale and paced distances were adjusted proportionately. This technique proved to be quite rapid and enabled a very detailed plan of the soil pattern to be constructed (see Figs 14 and 15).

The emerging soil pattern revealed a far more complex pattern of sedimentation and erosion by wind deflation on the fans than had been estimated following the early initial comprehensive traverses and preliminary traverses, or from air-photo interpretation alone.

(d) <u>Detailed quadrants</u> - A further method employed to determine the amount of variation occurring within soil mapping units was that of intensive studies of one acre plots. Three such areas were examined (Fig. 3):

1. on the surface of the Orari fan,
2. on the Meikleburn floodplain, and
3. on the lower part of the Meikleburn fan (Figs 11, 12, 13).

These examinations were carried out by initially establishing a chain grid over the acre quadrat. Inspection pits were dug at each grid intersection. Following an examination of these profiles the extents of subtypes and phases thus established were located by auger and pit inspection, systematically along grid lines and randomly over the quadrat. Prior to commencing the traverse, a grid was established on graph paper and subtype and phase boundaries were plotted in the field during the quadrat examination.

The variability encountered was particularly marked on the imperfectly and poorly drained soils of the Meikleburn floodplain, but was also quite distinct within the other two quadrats. The results obtained may indicate too fine a degree of differentiation of units for the demands of the required final information. It is interesting to note, however, that Protz et al (1968) were able to determine an even greater number of differing units, over a similar area, using only the thickness of horizons as their measured variables. Certainly the results have shown the extent of inclusions within soil types; and have more than adequately emphasised the need to study the soil pedon (USDA, 1960) when considering the characterisation of a soil type rather than an individual profile or series of profiles.

The observations based on the results obtained from these detailed transects and quadrats will be discussed later.

4. <u>Descriptive Terminology</u>

(a) <u>Site descriptions</u> - In all cases in the description of site characteristics, terminology employed by Soil Bureau (Taylor and Pohlen, 1962) was utilised. However, in some cases it was found that this terminology was not sufficiently detailed to assist in the explanation of site differences. In such cases additional terms were used:

(i) in relation to terrain:

e.g. "normal moderately sloping hillside

upper slope
mid slope
foot slope

convex hillsides #
concave hillsides #

(# in part after Clarke (1957) -'slope form of complex slopes')

In this case on all hillslides concave areas on all angles of slope were accumulative, but convex hillslopes were only accumulative on gently, moderately and some strongly sloping hillsides.

(ii) geomorphic terminology:

'fans' - In order to differentiate the surfaces of detrital accumulation adjacent to, and extending away from the mouths of eroding valleys, the so-called fan surfaces have been divided into three categories dependent upon the angle of slope. These subdivisions also reveal a decrease in degree of sorting and a general increase in the coarseness of the detrital material.

'low level fans' - (1^{o} - 4^{o} slopes) - the extensive fan system of the two main rivers and the Meikleburn stream. These are "alluvial fans" of Cotton (1948), and "fans on the old flood plains" of McCraw (1968), or in the case of the Mowbray area, where these three fans have coalesced to form a "basin plain" (Cotton, 1948 p. 259).

'low angle fans' - (5^{o} - 12^{o}) - these are the true "alluvial fans" of Cotton and are found at the entrances to narrow eroding gullies. They correspond to the "fan head" and "middle fan" zones of McCraw (1968).

'high angle fans' - (12^{o} +) - these are "alluvial cones" of Cotton (1948 p. 255) and are differentiated from screes in that they are moderately well vegetated and relatively stable.

'screes' - The general term 'scree' or 'talus slope' was not sufficient to adequately describe the range of features of this form occurring in the Mowbray area. The term 'scree' is retained in its original meaning (Cotton, 1948 p. 238-40) but emphasis is placed on the observation that the angular fragments of broken rock forming the surface of a scree do not, as a rule, remain long enough in place to become weathered and allow the formation of a soil. Such screes in the Mowbray fall into two divisions:

(1) currently "active screes", and

(2) "old screes" from which the bulk of the fines have been removed by wind and water, lichens coat the rocks and matagouri (Discaria toumatou) and mountain ribbonwood (Hoheria glabrata) grow out from amongst the large stones and boulders.

In addition to these a separate feature herein termed a "loamy scree" also exists in the Mowbray area, and in related high country areas. These screes have been formed by the severe erosion of soils generally leaving only the lower part of the subsoil. Running water has tended to remove the greater part of the fines from the upper profile, concentrating the coarser fragments. Subsequent movement due to creep and solifluction has given rise to an intimate mixture of rock fragments and a gritty silt loam (i.e. basically a loam) matrix. Continuous stone pavements rarely occur as such on these 'loamy screes'. 'Loamy screes' have been classified as "Incipient or Immature Screes" by O'Loughlin (1965 p. 17). In the Mowbray area screes usually stand at angles of between 28° and 35° with an average of 32°, which is similar to that quoted by O'Loughlin.

(iii) In relation to drainage the term "somewhat impeded" has been used and it is visualized as a drainage criterion halfway between the conditions "imperfectly" and "moderately well drained" and often used to embrace both. It should not be confused with "impeded drainage" of Clarke (1957). In order to elaborate on external drainage characteristics, the following two site features are recognised as well as the "normal site" (Taylor and Pohlen, 1962 p. 29) which has a medium runoff rate.

"Shedding sites" are those areas which permit rapid runoff either due to slope, compact surface horizons, poor vegetative cover, poor permeability or any combination of these. These are sites exhibiting "rapid runoff" (Soil Survey Staff, 1951 p. 167).

"Receiving sites are those areas, down slope from shedding sites, which receive greater amounts of water by runoff than similarly positioned sites which are not below shedding sites. These are sites which exhibit 'slow or very slow runoff' (Soil Survey Staff, 1951 p. 167).

(b) Profile descriptions - The description of soil profiles was in conformity with Taylor and Pohlen (1962). Soil colours (including mottles) unless otherwise stated were recorded moist. Channels and other voids were described in accordance with the abundance and size limitations laid down for pores (Taylor and Pohlen, 1962 p. 99) and clayskins were described in terms of origin (ibid p. 179) and relative abundance as assessed with reference to a visual percentage chart (ibid p. 79). Roots were not adequately discussed by Taylor and Pohlen and a modified form (Ives, 1966) of Clarke's (1957 p. 102) descriptive terminology for roots, pertaining to quantity and size was adopted.

The descriptions of stoniness followed Taylor and Pohlen (1962 p. 88) with the addition of "extremely stony", more than 60% stones (or gravel), and with the very stony class being modified accordingly. Terminology used to indicate soil depth was not definitive enough for the requirements of this survey and the following reallocation of limits is proposed:

very shallow	0 — 6"
shallow	6 - 12"
moderately deep	12 - 18"
deep	18 - 36"
very deep	36 +

These terms refer to the depth to agronomically contrasting layer, or the C horizon, (i.e. the base of the solum) whichever is the shallower.

2. CORRELATION OF MAPPING UNITS

Once the tentative legend had been established and the range of soils within each unit ascertained by intensive field investigation, there was a need to correlate these units with existing soil series and types established and documented by the Soil Bureau and others (see Table 2).

(a) Initial Difficulties Encountered

These were two-fold. There appeared to be, in many publications, a confusion between writers as to the true concept of a particular soil (see later notes on Tekoa and Kaikoura soils especially). This was particularly true in the case of the soils on steep slopes where many workers considered that they were on Kaikoura soils simply because they happened to be in the so-called 'zone' of Kaikoura soils as defined by Gibbs et al (1945) and Gibbs and Beggs (1953). Vucetich (1961) recognised this factor and referred to Kaikouran Steepland soils rather than Kaikoura steepland soils (following Raeside, 1956 p. 23) and implying that a wide range of Kaikoura-like soils existed which did not necessarily conform with the modal concepts envisaged by Gibbs et al or Gibbs and Beggs.

Secondly, as a natural consequence of that above, a proliferation of slightly different descriptions for the same soil type appeared. Soils were rarely if ever defined in terms of their morphological (and chemical) range and as a consequence, overlapping of defined units of soils resulted.

TABLE 2 - Sources of Information Relating to the Morphology and Chemistry of Soils Similar to Those Found in the Mowbray Area

SOIL SERIES	Gibbs et al 1945 (series & types)	Raeside & Baumgart 1948 (type)	Barker 1953 (set)	Gibbs & Beggs 1953 (series & types)	Tussock Grasslands Res. Com. 1954 (set)	Wells & Saunders 1956, a & b, 1957, (1960)	Thornton 1958 (type)	Raeside et al 1959 (type)	McDonald 1961 (type)	Cox & Mead (1963) (Series)	Fox et al 1964 (types)	Molloy 1964 (types)	Ward et al 1964 (types)	Soil Groups of N.Z. 1964 (types)	Fitzgerald 1966 (types)	Kear et al 1967 (types)	Vucetich 1969 (sets)	Soil Bureau Staff 1968a (sets)	Soil Bureau Staff 1968b (sets & types)
Sherwood																x		x	
Opuha		-				+		x						x		x	-	x	-
Tengawai																x	-	x	
Wakanui								x		-	x		x			x	-	x	
Skipton								x								x		x	
Clayton (ns)																			
Kakahu								x			-					x	-	x	-
Meikleburn (ns)																			
Ashwick																x		x	-
Mowbray (ns)																			
Kirkliston																		x	
Lookout (ns)																			
Puketeraki																	-	x	*
Kaikoura	x		-	x	-	+			+			x		x			-	x	
Tekoa				x		+	+					x					-	x	
Taitapu								x		-	x		x		x	x	-	x	*
Tasman	x			x										x			-	x	

(ns) = new series name

KEY:
- \- Broad outline of morphology
- \+ " " " " with detailed chemical, biological or physical data
- x Detailed morphology with routine chemistry
- * Soil Bureau reference profile with detailed morphology, chemistry, physics and mineralogy.

e.g. Skipton silt loam:

7" pale grey silt loam, weakly developed crumb structure, friable, few small rusty flecks,

4" pale grey silt loam, weakly developed nutty structure, friable, powders when dry, many rusty and orange mottles,

8" pale yellow silt loam, blocky structure, firm, hard when dry (hard pan),

on yellow silt loam, blocky structure, firm, hard when dry.

(Raeside et al, 1959 p. 25) and

Skipton silt loam:

9" dark greyish brown, firm silt loam,

11" pale yellowish brown, friable silt loam with very many reddish yellow mottles,

on pale yellow, firm, massive silt loam with many orange mottles.

(Kear et al, 1967)

If these are considered as the extreme (?) ranges of the Skipton series it can be easily seen how correlation on a morphological basis only becomes difficult and duplication arises. Consider:

7" dark greyish brown, very friable silt loam with crumb and nutty structure,

6" pale greyish brown, friable silt loam with blocky structure,

8" pale yellowish brown, strongly mottled, firm heavy silt loam with blocky structure

on yellowish brown, massive, very firm, heavy silt loam.

(Soil Bureau Staff, 1968a)

which in the writer's opinion is an acceptable profile within the apparent range of the Skipton soils as shown above, or:

8" dark greyish brown, friable silt loam,

12" pale yellowish brown, friable, heavy silt loam on pale yellow, very firm, massive silty clay loam,

which according to Kear et al (1967) displays "rusty brown mottling in the subsoil" in certain locations. These two profiles would both be acceptable morphologically within the apparent range of the Skipton soils, yet they have been quoted in soils publications as being respectively typical of the Opuha and Sherwood silt loams. Certainly all of these soils are terrain associated, but when the Opuha soils "grade into the Skipton soils" (Kear et al 1967 p. 31) where does one place the pedological boundary? Similarly, the differentiation between Opuha and Sherwood soils seems to be rather ill-defined. Morphologically it is based on better structural development in the latter and the seeming occurrence of colder winters with some snow in regions where the latter is mapped. The better structure, in fact, in the Sherwood soils exists only in the A horizon and may merely be a consequence of current and past land use (Packard and Raeside, 1952).

Similarly, a search of the literature reveals wide reported ranges for certain high country yellow-brown earths, (e.g. the Kaikoura and Tekoa soils particularly), while others are restricted in range by only one or two profile descriptions. Where there is only a minimal number of profile descriptions such soils may fall comfortably within the range of "apparently" more precisely documented soils. In particular the Benmore and Kirkliston soils show distinct similarities with the accepted morphology of both Kaikoura and Tekoa soils.

One would think that the chemistry of soils would be an aid in their definition. This is so on a very broad basis only and the bulk of the routine analytical data is at present of little differential use at detailed survey level. This is because of a paucity of information, perhaps only one or two analyses, for certain soils and a veritable wealth of information indicating a very wide range of soil conditions for other well documented soils. For example, Soil Bureau records contain only one analysis of a Skipton soil, and only two of Sherwood soils, while on the other hand nine (almost whole) profile analyses of the Tekoa soils reveal a very wide variation in chemical character (see Table 10).

(b) Determination of Medial Profiles

Because of the lack of precise definition of various units, and the lack of documentation on observed ranges, it was decided to construct medial profiles for the various soils likely to occur in the Mowbray area. To this end data on several soils was assembled not only from existing publications but also from unpublished material in Soil Bureau records.* Morphological, site and analytical data were recorded for each soil series or set, and from this one was able to determine the range of conditions under which each soil had developed; and the range in the character of the profiles' morphology and chemistry. A composite or medial set of conditions could then be established and the degrees of variation from these conditions noted. The medial concept of each series or set as determined is given in the preamble to the description of each series in Chapter V below.

At all times during this study the nomenclature assigned to each soil set, series or type by the Soil Bureau Staff was accepted without question and no attempt was made to regroup soils which

* The writer is particularly indebted to Messrs James D. Raeside and Michael L. Leamy for permission to peruse records housed in Soil Survey offices in Christchurch and Dunedin.

had apparently anomalous characteristics for their assigned set, series or type. Any attempt to regroup profiles into more appropriate sets etc. would have involved more comprehensive examination of records than was undertaken and, if practical, would involve discussion with the surveyors responsible for the descriptions and correlations. Time precluded the conducting of such an investigation. Due allowance was made for the differences in detail and accuracy required in the preparation of medial, or the selection of reference profiles at various levels of mapping.

(c) System of Correlation

Once a medial profile and the range of morphological and chemical characteristics had been established it proved a relatively simple matter to effect correlation between recorded profiles from the Mowbray area and established soil series. A system was devised to present a completely subjective approach. This entailed a soil series of common environmental and site factors being compared with the morphological range and chemical features of one of the Mowbray soil units, in accordance with the scheme illustrated by Table 3. The whole basis of such system is that soils should be correlated on similarities and not differences. Hence the established soil which has the greatest number of similarities with the soil being correlated should give its name to the unknown soil.

Such a system places much greater, and equal, emphasis on morphology and chemistry than has been assigned to the identification of soils in the past. This should be the basis of differentiation of soil types at detailed levels. Variations in broad climatic, topographical and vegetational aspects are satisfactory criteria for determining broad soil trends and for

Table 3 - Schematic Correlation Table

Correlation Sheet*: Profile ...

Chemical data (whole profile)

Comparisons made on the basis of:

pH. (a) actual values

(b) trends down the profile

%C (a) relative level in A horizon

(b) contrasts in levels between A and B horizons

C/N (a) actual values

(b) trends down the profile

CEC (a) actual values - bearing in mind differences in organic matter content

(b) trends down the profile

TEB (a) actual values - greatest emphasis on B and C horizon

BS% (a) actual values

(b) trends down the profile

Exch Cations

- general consideration of actual levels - especially Ca, Mg, and K - but special emphasis on trying to match Mg and K values down the profile

Where the profile discussed has a characteristic within the accepted range of a given soil set/series/type, the name of that set/etc is recorded in the appropriate place. The number of times each soil name appears is then noted at the bottom of the column.

Morphological data (each horizon)

A horizon within:

(a) colour range of ......

(b) structural range of ......

(c) mottles/stones compare with ......

B horizon within:

(a) colour range of ......

(b) textural range of ......

(c) structural range of ......

(d) mottles)
stones) compare with ......
compaction)

C horizon within:

(a) colour range of ......

(b) textural range of ......

(c) structural range of ......

(d) mottles)
Stones) compare with ......
compaction)

Elevation - within range of ......

Terrain - within range ......

The total number of times a soil set/series/type name appears in this column is recorded and these totals are then added to totals obtained by summation in the left hand column.

The soil being correlated is then given the name of that series/type with which it has the greatest number of similarities. Should the soil being correlated have an equal number of similarities with two or more soils it should be correlated with that soil with which it has the greatest morphological similarity.

Correlation ....

Other soils .... (in decreasing order of similarity)

* Only those soils of comparable environmental range should be used for correlation.

differentiating soil sets but should be restricted to a secondary differentiating role in the identification of soils during detailed surveys.

3. CONSTRUCTION OF SOIL MAP

The base map used in the preparation of the final map showing the distribution of soils in the Mowbray area (see pocket at rear) was provided by the Director-General of the Lands and Survey Department. Enlargements at a scale of one inch to 20 chains were provided for the eastern one third of sheet S.90 and the western one third of sheet S.91. In the case of S.90, the maps provided were enlargements of prints prepared at a scale of 1 : 25,000 for N.Z.M.S. 2, whilst those from sheet S.91 were enlargements of the 1 : 45,000 compilation plot prepared in 1967 for that sheet.

(a) Phase 1 - Use of Air-photo Enlargements at a Scale of Approximately One Inch to 20 Chains

Because one inch to 20 chains air mosaics were not available enlargements of the air-photos covering the area were obtained. Boundaries between units established during the initial air-photo analysis were transferred from the photographs to the photo-enlargements. The enlargements were then taken into the field and the boundaries so established were either verified or relocated. On longer and more difficult traverses it was not possible to take the enlargements (unless they were cut to a smaller size, which did happen for some traverses) and consequently field notes taken during the traverse were applied to the enlargement in the office. Extrapolation of boundaries in areas not visited during traverses was based on air-photo analysis.

(b) Phase 2 - Re-location of Boundaries on Air-Photos

Boundaries either verified, re-located, removed or added on the 20 chain photo enlargements were then transferred back onto the air-photos (at a scale of one inch to 50 chains) by inspection. It was considered necessary to return to the original photographs for plotting soil boundaries because of the inherent scale distortion and image displacement in air-photos covering rolling, hilly and steep terrain and the exaggeration of those errors on direct photo enlargements. (Avery 1968, USDA 1966 p. 10).

Boundaries separating soil units on nearly level or flat terrain were, however, able to be plotted directly from the photo enlargement onto the 20 chain base map. Scale was adjusted by the use of an enlarging projector. In flat country image displacement is negligible (USDA 1966) and the facility to constantly adjust scale removes, to a large extent, scale distortion away from the photo centre (Avery 1968).

(c) Phase 3 - Plotting Boundaries from Air-photos

Boundaries marked in areas other than on the larger more extensive areas of flat, or nearly level land, were taken off air-photos with a "radial line plotter". The "radial line" principle is based on intersection and resection in triangulation, a basic survey principle (Lahee 1952). The flight line between the centres of stereo-pairs serves as a base line and points away from the base lines are located by intersection, with concurrent stereoscopic observation using a co-mounted mirror stereo scope (Ray 1956). Because objects are viewed stereoscopically the intersection of the two arms will indicate the true map position of the object and hence apparent image displacement seen when the photos are viewed planimetrically is negated.

The radial line plotter is probably the most accurate rapid method of transferring data from air-photos to base maps. It is certainly more accurate, especially in hilly and mountainous areas than more rapid techniques, notably the use of "sketch-masters" (Rijkse 1966, Ray 1956), but one serious limitation is its lack of ability to correct for tilt (Ray 1956). However, as the base maps had already been drawn by the Lands and Survey Department, and control lines in the form of streams and roads were also transferred from the air-photos, it is considered that few errors due to tilt or scale distortion exist.

(d) Phase 4 - Enlargement to One Inch to 20 Chains

Although the radial line plotter used had the facility to enlarge up to two times photo scale, this still would not have been sufficient for direct plotting onto a base map at one inch to 20 chains. Consequently data taken off the photographs with the radial line plotter was enlarged only to a scale of one inch to 40 chains. This information was then enlarged two times and projected, with an enlarging projector, directly onto the base map. The use of a base map with control lines already marked enabled an accurate scaling and hence location of soil boundaries from the enlarged 40 chain plot.

Although this procedure may appear both long and involved, it was the only method consistent with the accuracy of the field work which allowed the accurate yet rapid production of a soil map at the scale required. It is common practice in soil survey to map soils at a larger scale than that intended for final publication (Soil Survey Staff 1951 p. 16, Leamy and Panton 1966, Barrera 1961, Taylor and Pohlen 1962 p. 145). Consequently the effects of errors inherent in the production of field maps are considerably mollified when the final maps, at smaller scales, are produced.

In mapping the soils of the Mowbray area the final map appears at the same scale as the field map, yet in the process of production data has been reduced and enlarged again. Thus despite attempts to maintain high standards of accuracy, errors due to plotting and the location of boundaries on the field map may have been exaggerated on the final map. It is because of this that the map is probably only accurate to within 50-25 yards (1/8 to 1/16th inch on the map) along traverses and away from traverse lines errors may be as much as 100 yards (which is ¼ inch on the map).

4. LABORATORY STUDIES

(a) Chemical Analyses

In order to assist in the correlation of the soils of the Mowbray area with soils occurring in adjacent regions, routine (Metson 1961) chemical analyses were carried out on soil samples from 15 profiles. The following determinations were carried out:

(1) pH - Measured with a glass electrode using 10 grams of soil to 25 ml of distilled water and standing overnight.

(2) Total Nitrogen - Determined by the semi-micro Kjeldahl method (Metson 1961, p. 58, 59).

(3) Organic Carbon - The method of Walkley and Black (1934) and Walkley (1947) was employed, using potassium dichromate and final titration against ferrous ammonium sulphate. This method recovers only 77% of the organic carbon present in the sample, consequently values obtained were x 1.3 to give a total organic carbon figure.

(4) Cation Exchange Capacity - CEC was determined by Kjeldahl distillation of ammonia following leaching with

ammonium acetate and washing with ethanol, and final titration against 0.1N.HCL using a mixed indicator (Metson 1961 p. 105).

(5) Exchangeable Cations - To the NH_4OAc leachate from the CEC determination was added sufficient $SrCl_2$ to give a concentration of 2000 ppm Sr^{2+} ions, and the whole was made up to 250 ml. Levels of exchangeable bases were then determined, following comparison with a series of reference samples, by the methods in the table below.

Cation	Method	Wavelength	Instrument
Ca^{++}	Flame photometry	422 nm)	Tetron 100 Atomic Adsorption Photometer
Mg^{++}	Atomic Adsorption	385 nm) with tube)	
K^{+}	Flame photometry	K filter	X 117 EEL Flame Photometer
Na^{+}	Flame photometry	589 nm	Tetron 100 AA Photometer

(6) Total Exchangeable Bases (TEB) - TEB was derived as a summation of the levels of exchangeable bases in each sample (Metson 1961, notes p. 105).

(7) Base Saturation (BS %) - By calculation

$$BS = \frac{TEB}{CEC} \times \frac{100}{1} \%$$

(8) Phosphorus - A semi-detailed phosphorus fractionation was carried out so that comparisons might be made with other areas in order to determine the stage of weathering of the soils (Walker 1965, Stevens 1963).

i. Total Phosphorus - $Na_2\,CO_3$ fusion with digestion in 1 : 1 HCl.

ii. <u>N H_2SO_4 soluble P.</u> - soils were shaken overnight with N H_2SO_4 and then filtered.

iii. <u>N H_2SO_4 soluble P. after ignition</u> - soils were ignited at 550°C for one hour and then extracted in the same manner as (ii) above.

Total Phosphorus was determined by the Dickman and Bray method which was modified by Fife (1959). This involved the formation of the phospho-molybdate ion and the measurement of colour intensity with a "Spectronic 20" at 825nm.. Phosphorus soluble in sulphuric acid was determined by a modified Fogg and Wilkinson technique similar to the "Molybdenum-blue" method described by Metson (1961) pp. 42-45). Colour development was measured with a Spectronic 20 at 625nm..

N. H_2SO_4 soluble P was considered to be easily available phosphorus (Pa) - although some discussion is centered on this point (Shah et al 1968).

(N H_2SO_4 soluble P after ignition) - (N H_2SO_4 soluble P) is considered to equal organic phosphorus (Po).

Fixed phosphorus or difficulty available phosphorus (Pf) was calculated by subtracting N H_2SO_4 soluble P after ignition from total phosphorus (P_T) - thus:

$$Pa + Po + Pf = P_T \qquad \text{(Walker 1965)}$$

(b) <u>Mineralogical Analyses</u>

In an attempt to obtain additional information in support of genetic theories developed from a consideration of profile and site occurrences and morphology, it was decided to examine the mineralogy of the crystalline clay fraction. Initially only X-ray diffraction techniques were employed for A, B and C horizons of all profiles sampled. Extra techniques were used at a later date to confirm the presence or absence of certain minerals.

(1) X-ray Diffraction -

i. Preparation of samples - soils were prepared in accordance with the procedure detailed by Claridge (1969 pp. 7-15), with the exception that citrate/dithionite extracts were discarded and the sand fraction as separated by centrification was not fractionated further.

ii. Examination of samples - the instrument used was a "Phillips PW 1310 diffraction unit". Instrumental conditions were as follows: 50 kV and 20mA, using an all vacuum tube, iron anode operated at divergence, receiving and scatter slits of 1^{o}, 0.1^{o} and 1^{o} respectively with an Mn filter. Reflection was recorded with a proportional counter, a scanning speed of 1^{o} of 2 per minute was used, and pulse height selection was employed. The slides examined were:

(i) Mg saturation with glycerol solvation at $20^{o}C$

(ii) K saturation at $20^{o}C$

(iii) K saturation heated to $375^{o}C$

(iv) K saturation heated to $550^{o}C$

Wherever possible the K^{+} saturated clay slide was also the one which was heated to $550^{0}C$. In addition a pre-heating to $375^{o}C$ took place and slides were X-rayed before final heating to $550^{0}C$ and re - X-ray examination.

Mineral identification was in accordance with the principles outlined by Mackenzie (1967) and procedures detailed by Claridge (1969) and particularly Fieldes (1968b) for the identification of the inter-stratified minerals. Estimation of the relative abundance of the crystalline clay minerals identified followed the method outlined by Johnson et al (1963) as adapted for New Zealand conditions by Fieldes (1968b) and Claridge (1969).

(2) Differential Thermal and Infra-red Absorption Analyses

For certain minerals, particularly matahalloysite and gibbsite, positive identification was not possible due to interference by second and third order reflections from interstratafied materials. In order to confirm the presence or absence of suspected minerals, a number of whole soil samples were subjected to DTA or IR Absorption after being ground to pass 100 mesh. In the case of the DTA the inert reference was calcined kaolin, whereas the IR absorption technique involved the formation of potassium bromide discs under a pressure of 10 tons. In all cases reference patterns were used to determine the presence or absence of minerals.

CHAPTER IV

FACTORS OF THE ENVIRONMENT

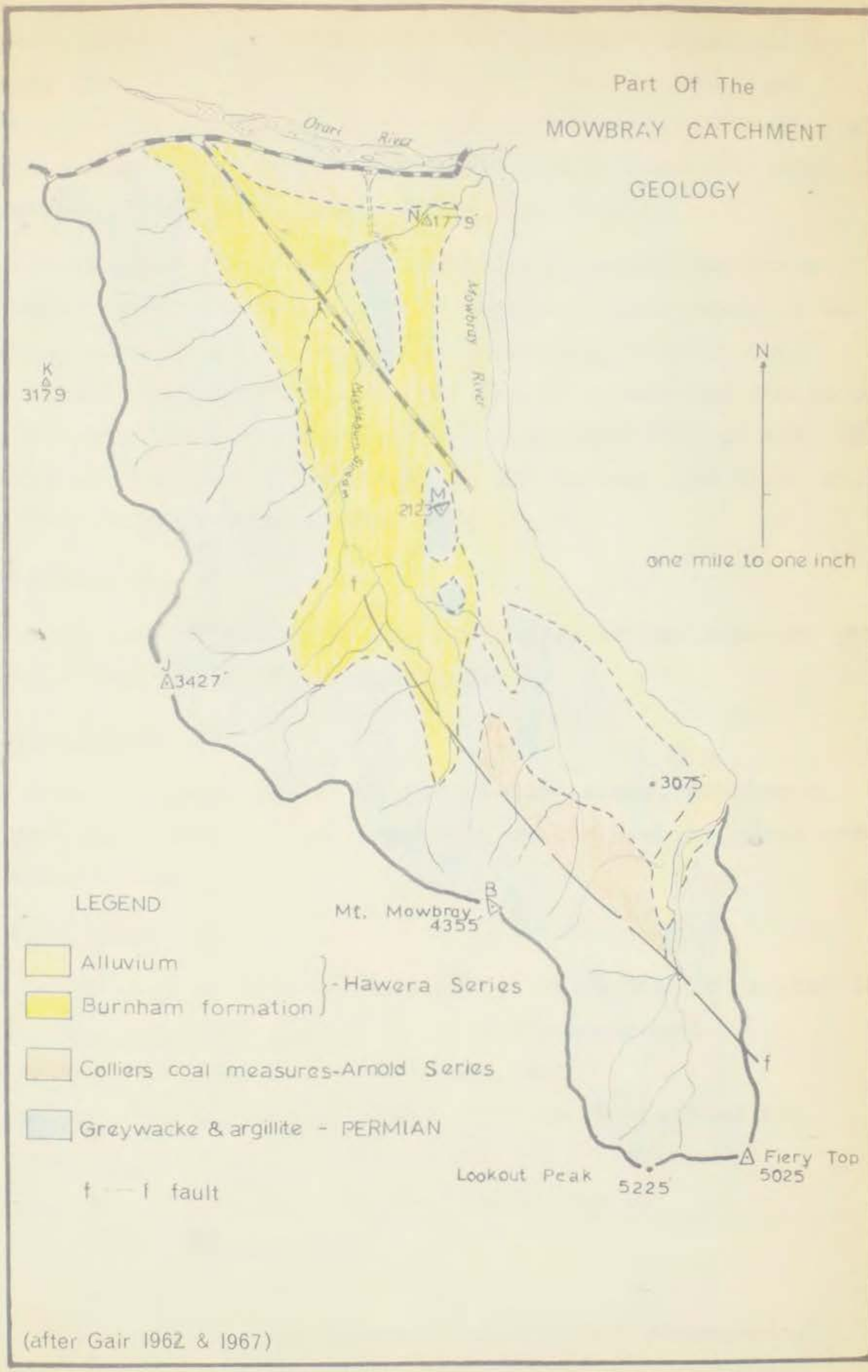
1. GEOLOGY

The basement rocks of the area are principally greywackes and argillites within which Gair (1962) found little macroscopic evidence of metamorphism. On the basis of the occurrence of fragments of what was considered to be the lamellibranch Atomodesma sp. they were thought to be of Permian age. Later Gair (1967) considered that these rocks were of Chlorite 1 zone metamorphic grade and noted that they were of medium induration.

A small, infaulted, outlier of Tertiary rocks of Arnold series (upper Eocene) age occurs on the divide between the head of the Meikleburn stream and the Mowbray (see Fig. 4, Gair 1962). Gair considered these to be part of the Colliers Coal Measures formation and noted that they consisted of stratified brownish-cream carbonaceous quartz sands over white quartz sand with pebbles; the junction between the two being identified by a thin bank of sandy lignite. Apart from a small local accumulation of outwashed quartz sands these sediments which are unconformably overlain by colluvial greywacke debris have no influence on soil formation in the area (Plate 4).

The older terrace and fan deposits have been correlated by Gair (1967) with the Burnham formation of the central Canterbury area. This formation has been allied with the Blackwater advance of the Otiran glaciation and has been correlated by Suggate (1965) as having an age of from 22,300 to 20,000 years. However, in the light of work carried out by Cox and Mead (1963), who considered that the soils of the Templeton surface (the

Fig. 4


Part Of The
MOWBRAY CATCHMENT
GEOLOGY
Orari River
Mowbray River
N
one mile to one inch
K
3179
N 1779'
M
2123'
J
3427'
3075'
B
Mt. Mowbray 4355'
Lookout Peak 5225
Fiery Top 5025
f
LEGEND
Alluvium
Burnham formation
- Hawera Series
Colliers coal measures-Arnold Series
Greywacke & argillite - PERMIAN
f — f fault
(after Gair 1962 & 1967)

Springston formation of Oborn and Suggate (1959) which was similarly correlated with the Blackwater advance) were aged between 3,000 and 6,000 years, it may be that the older alluvial gravels in the Mowbray area (shown as Burnham formation) are much younger in age that that suggested by Gair.

Deposits of recent alluvium occur adjacent to the Orari and Mowbray rivers and along the courses of the majority of the streams in the area. The later Quarternary history of the region will be discussed below. The nature and age of the floodplain, terrace and fan formations are discussed therein and consequently the Pleistocene deposits of the Mowbray catchment will not be discussed further in this section.

2. PHYSIOGRAPHY

The Mowbray catchment may be considered as two separate yet intimately related physiographic units:

(1) Upper Basin

The narrow upper valley of the Mowbray river, flanked by steep eroding hillsides, and separated by the Mowbray gorge and Lucas's Hill from -

(2) Lower Basin

A broad area of more subdued relief which may be divided into -

(a) the watershed upland - on the western and southern edges of the lower basin, and

(b) the area of fan coalescence - which occupies the central, northern and eastern sectors of the lower basin and is made up from the coalescence of

i. the Mowbray fan,

ii. the Orari fan,

iii. the Meikleburn fan and Meikleburn floodplain.

Included with each of these subdivisions of the "area of fan coalescence" are the minor low fans on the periphery of the "watershed upland".

The two stereograms (Plates 1 and 2) illustrate the two main regions and show the sub-regions within the "lower basin". Plate 3 offers a panoramic view of the "lower basin", as does the topographic sketch (Frontispiece).

(1) The Upper Basin

Confined at its lower end by the Mowbray gorge to the east of Lucas's Hill, this area is surrounded on the south and west by steep, eroding hillsides reaching 4000 to 5000 ft above sea level. (Plate 20) To the east and north similar terrain occurs, but 3000 ft is the maximum elevation attained. These hillsides are covered with talus material which has been stabilised by vegetation, but towards the head of the valley, and in the heads of tributary streams, unvegetated screes occur. Bare rock outcrops are also common in the head of the valley and on the southern and western watershed boundaries. The deep V-like incision of tributaries in this sector are indicative of current rejuvenation. A series of narrow terraces are developed at the northern end of the region and these can be traced through the gorge and onto the Mowbray fan surface of the "lower basin".

(2) The Lower Basin

Fringed by rolling, hilly and occasionally steep-sided ridges which culminate in the 3000-4000 ft ridge of the western watershed of the Mowbray catchment, this region is split by a central line of south to north oriented low greywacke hillocks (Figure 4 and apparent in Plate 3).

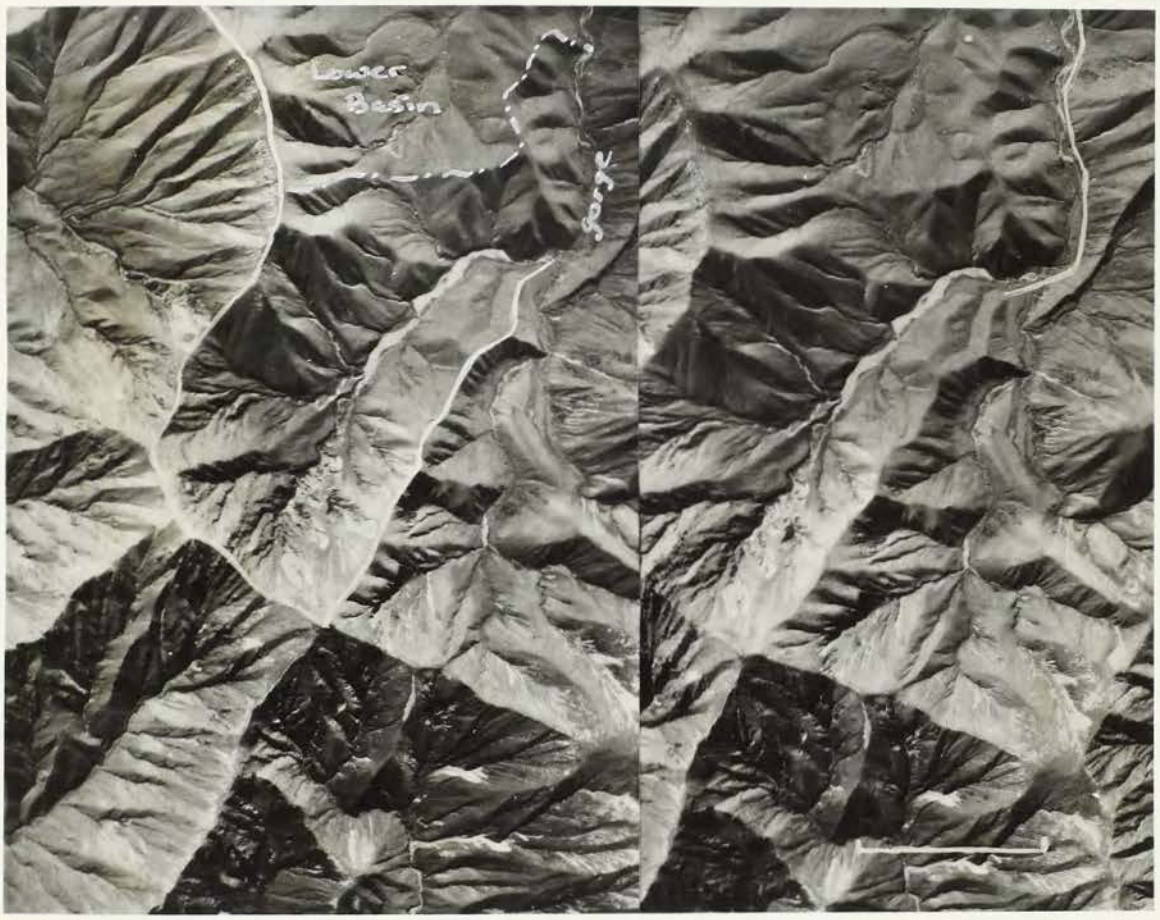


PLATE 1 Stereogram Showing the Upper Basin of the Mowbray Catchment

PLATE 2 <u>Stereogram Showing the Lower Basin of the Mowbray with the Area of Fan Coalescence in the Centre and the Watershed Upland on the Adjacent Hillsides</u>

(a) Watershed upland - the hillsides on the western and southern boundaries of this region, in contrast to the slopes in the "upper basin", show evidence of erosion only on the edges of their rounded summits. Upper parts of these hillsides tend to be convex, leading onto broad ridge crests of gentle slope. Lower slope locations tend to be concave and in contrast to that seen in the "upper basin", there is little evidence of active gully erosion. Often the lower courses of tributary streams, in this sector, are characterised by poorly drained alluvial soils.

(b) Area of fan coalescence - the fans of the Mowbray and Orari rivers converge towards the central part of the basin where they are separated by the floodplain of the Meikleburn stream (Plates 2 and 3). The Meikleburn stream rises in the area of the boundary between the two major regions and the small recent alluvial fan, and older fans, of this stream occupy the southwestern corner of the sub-region.

The fan surfaces slope at low angle towards the floodplain of the Meikleburn to the west of the line of low greywacke hillocks and represent the current stage of infilling of a basin of previously greater depth. Older fans, associated with the Meikleburn, are of greater slope and were probably initially formed when the basin was deeper and the Mowbray and Orari rivers were less actively aggrading.

In Chapter V the soils have been grouped together on the basis of their physiographic/parent material zone occurrence. The groups used in that Chapter may be equated with the physiographic regions as follows:

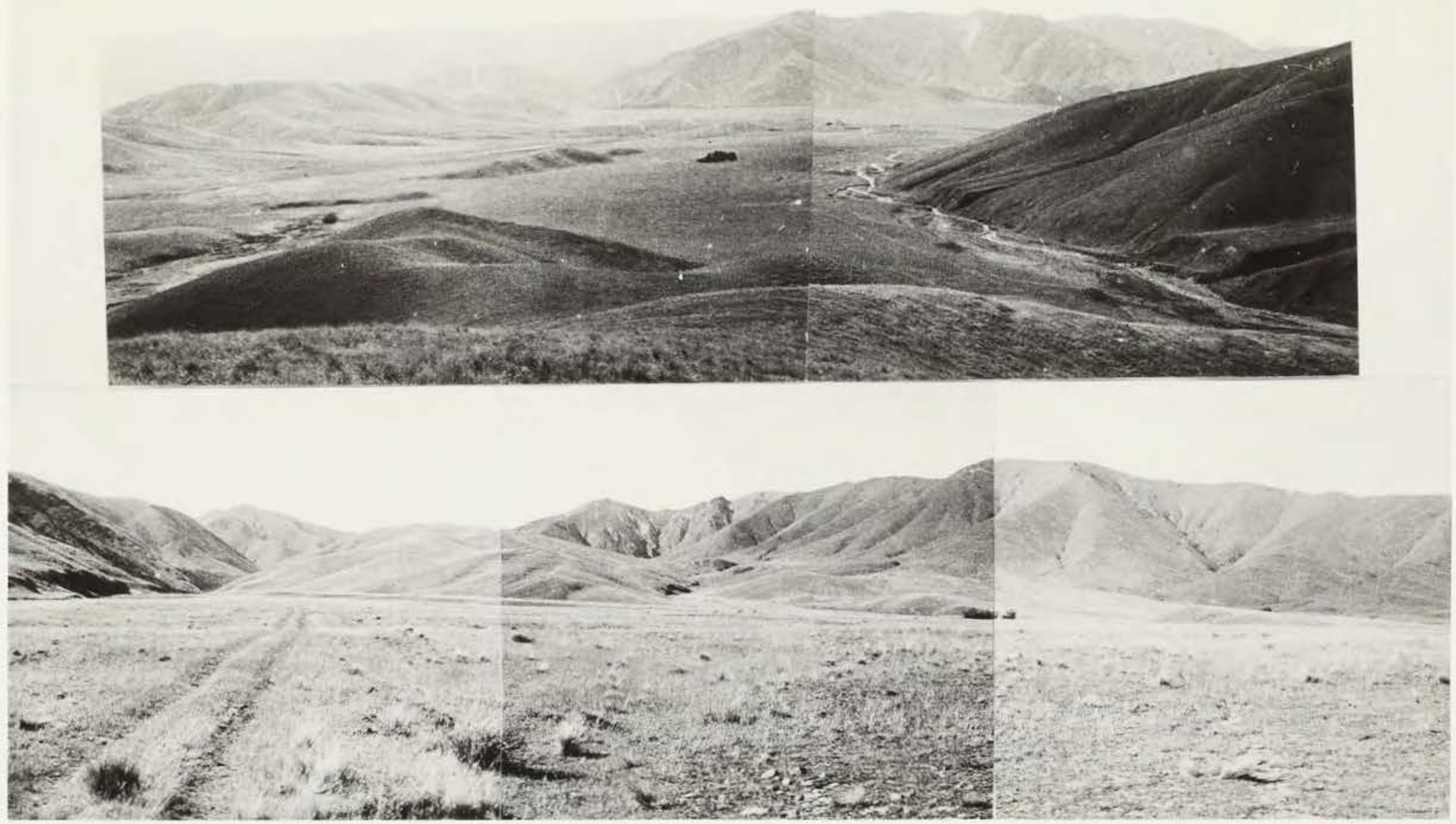


PLATE 3 Panoramic View of the Upper Mowbray Fan with the Southern Boundary of the Catchment on the Skyline (upper) and View of the Lower Basin (lower)

(1) Floodplains, levees and bottomlands - the floodplain of the Meikleburn stream and peripheries of the Orari and Mowbray fans.

(2) Terraces and younger fans - the area of fan coalescence and associated terraces in the gorge and upper basin.

(3) Older fans and rolling hillsides - the watershed upland, less the steeper areas right on ridge crests which are included with the:

(4) Hilly and steep hillsides - the upper basin.

3. CLIMATE

Complete meteorological records are not available for the Mowbray catchment but rainfall records from the study area have been kept since 1963 by the South Canterbury Catchment Board. One gauge at Meikleburn homestead has been read daily, the other, situated at the confluence of the two main branches of the Mowbray is read on a monthly basis. Over a five year period these two gauges at 1800 ft and 2300 ft elevations, have respectively recorded averages of 28.30" and 32.38" annual rainfall. Additional gauges within the whole of the upper Orari catchment do shed some light on the annual pattern of precipitation, which is shown in Figure 5.

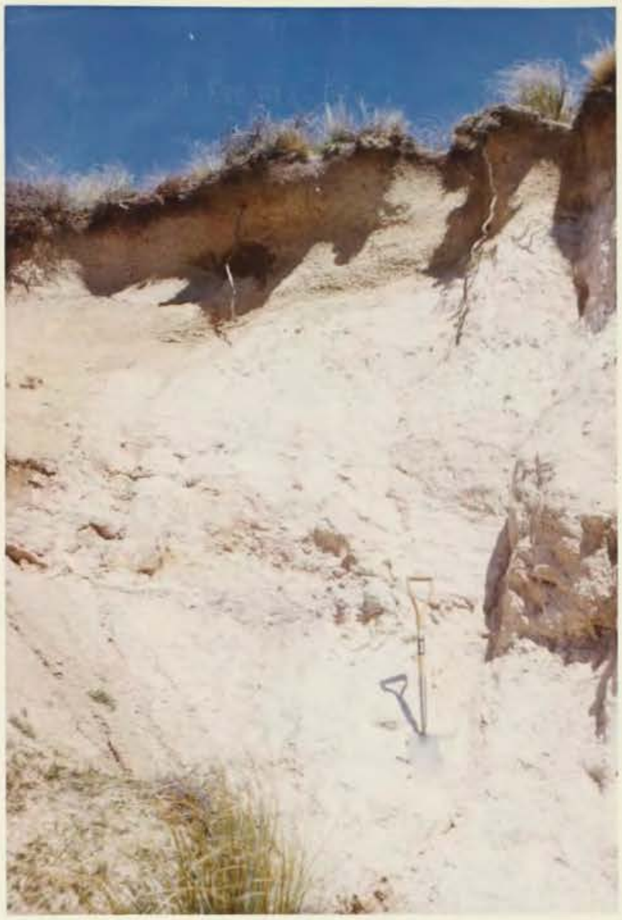


PLATE 4. Tertiary quartz sands (Arnold age) - overlain by colluvial creep material.

PLATE 5. Lower end of upper basin with Tasman, Ashwick and Mowbray soils on the terraces. Tengawai hill soils occur on the slopes on the right and on the left Lookout steepland soils.

Table 4 - Annual Rainfall at Various Stations Throughout the Upper Orari Catchment

SCCB No.	Site	Elevation ft.	Average Annual Precipitation
5	Lochaber homestead	1600	30.15"
4	Meikleburn "	1800	28.30"
6	Mt Peel Creek	2000	32.95"
7	Mowbray	2300	32.38"
3	Quartz Creek	2400 (approx.)	32.89"
1	Orari Saddle	2500	50.10"
2	Look-up Stream	2900	42.96"
8	Blue Mountain*	3400	35.26"

(* average over only two years records, all others based on five years observations)

Records supplied by courtesy of South Canterbury Catchment Board.

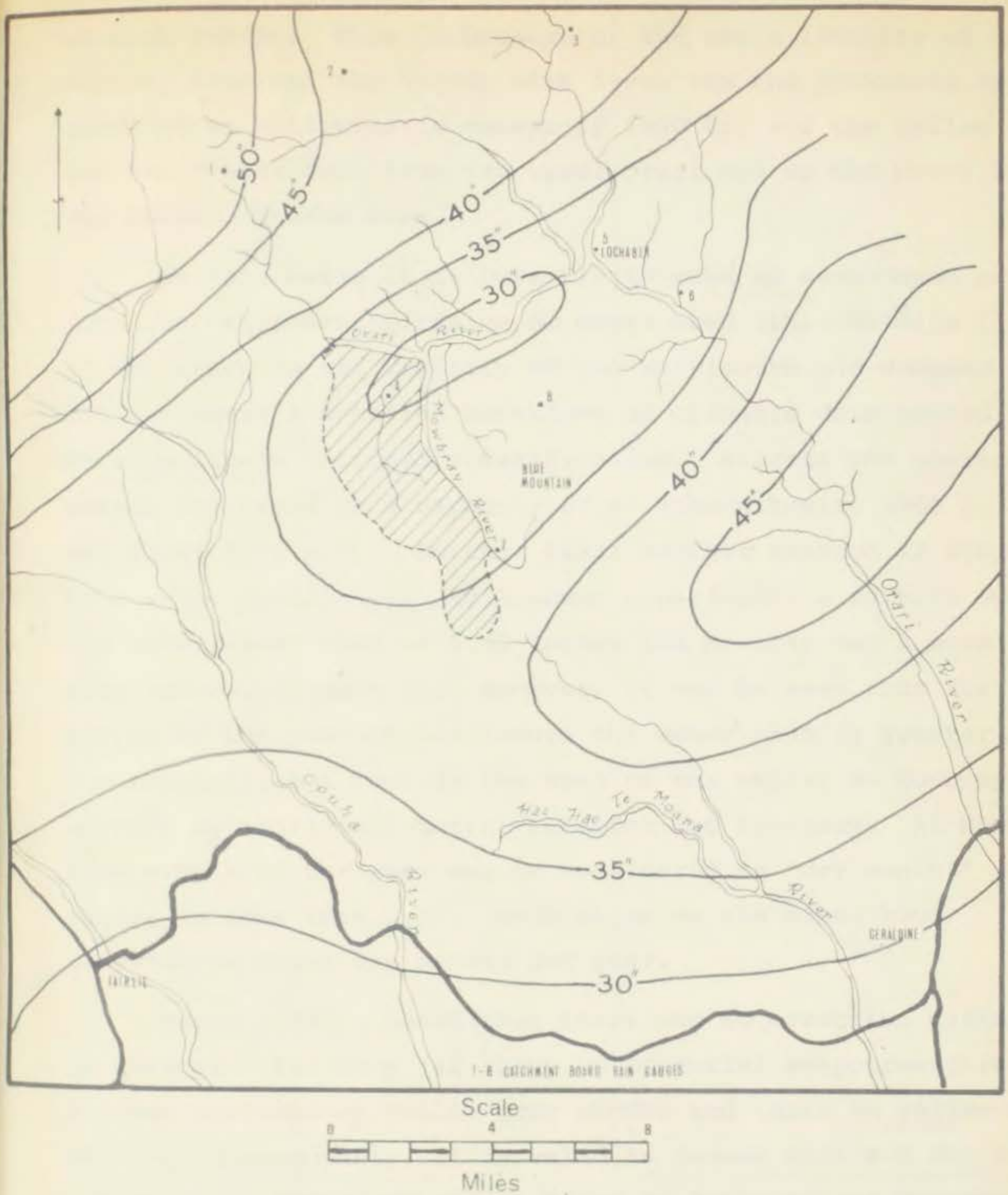
Annual distribution of rainfall is shown in Figure 6 for Meikleburn, Lochaber and Mowbray, and the extreme monthly ranges for the former two stations are also indicated. These may be compared with the annual distribution of rainfall for the two nearby meteorological stations of Fairlie and Lake Tekapo.

The Mowbray area seems to have a much greater month to month variation than either Fairlie or Lake Tekapo. The actual pattern of annual precipitation is remarkably similar for these two latter sites but this may be attributed to the relatively short period over which observations have been made throughout the Orari catchment.

While the average annual precipitation at Meikleburn is quite similar to that experienced at Fairlie, it is probable that the annual range of temperatures is closer to that measured

RAINFALL

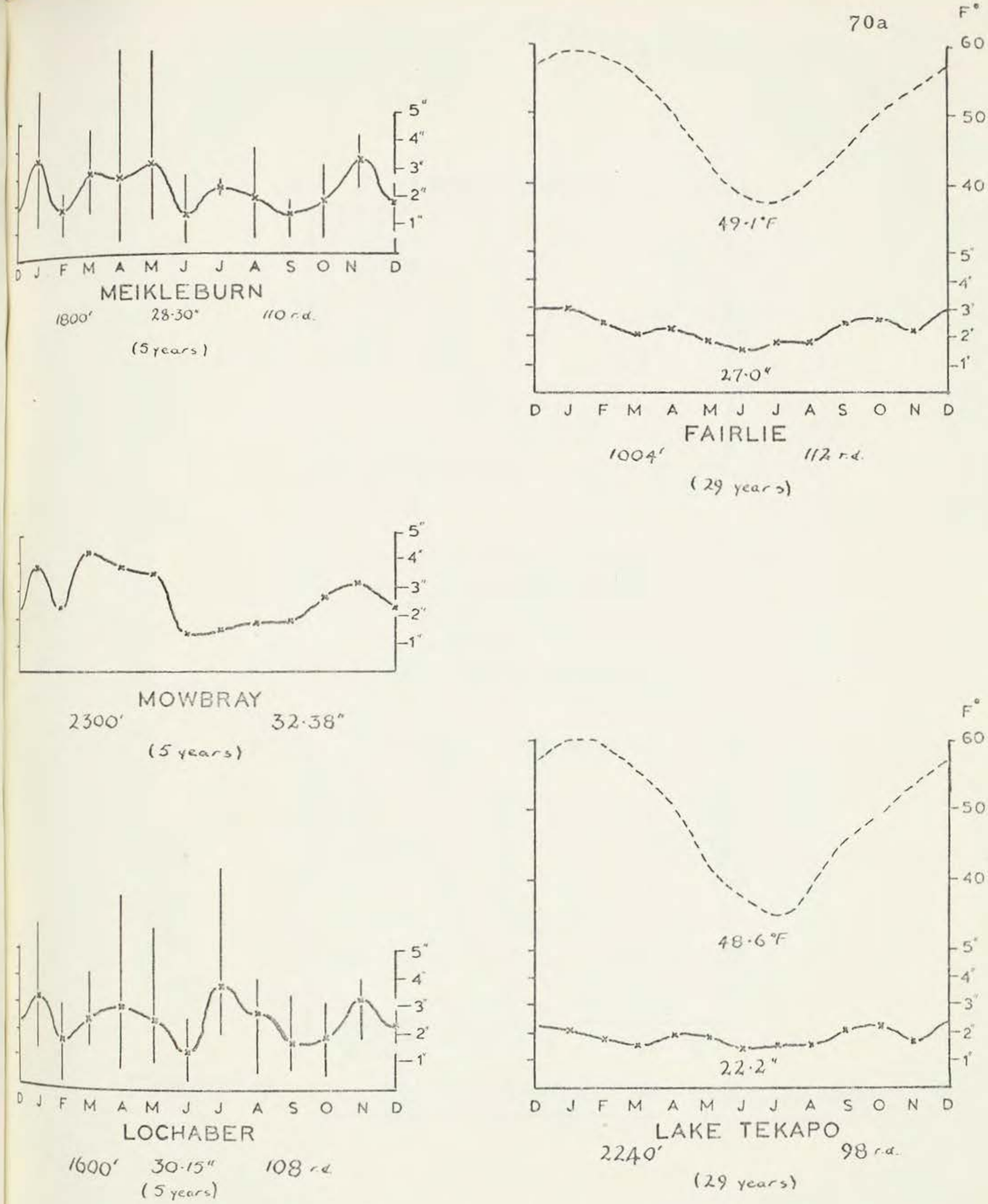
Fig. 5



at Lake Tekapo. This is because of the basin locality of the Mowbray area and the higher base level and the proximity of hills reaching to altitudes in excess of 5000 ft, and the influx of the nor'wester both from the upper Orari and up the Orari from the Phantom/Hewson area.

On this basis it is possible to make an assessment of the potential evapotranspiration or water need (Thornthwaite (1948) of the areas in the vicinity of the Meikleburn and Mowbray gauges. Table 5 shows a detailed breakdown of climatic data according to Thornthwaite's rational classification. Storage and storage change are based on a capacity of 4" (Thornthwaite 1948 p. 65 and Hurst 1951 p.7). On this basis neither station is subjected to a water deficiency. Meikleburn experiences a surplus over and above water need of 5.42 inches and Mowbray has a surplus of 9.50 inches, (Figure 7). However, it may be seen that for four months of the year at Meikleburn the water need is greater than the rainfall, but towards the head of the valley at Mowbray need exceeds rainfall only during December and February. At Mowbray four months of the year may be considered as "dry months" when runoff is less than 0.5". Meikleburn on the other hand experiences eight dry months per year.

Hurst (1951), noted that there was no essential difference in thermal efficiency (as shown by potential evapotranspiration) between stations on yellow-grey earths and those on yellow-brown earths. Consequently, it is valid to assume that P-E for the two rainfall recording sites, based on temperatures recorded at Lake Tekapo, will be almost identical. Hurst went on to note, however, the significance of the moisture index and surplus water in separating stations into either of these two main soil zones.



RELEVANT CLIMATIC DATA

FIGURE 6

— — Rainfall Temperature - - - - -

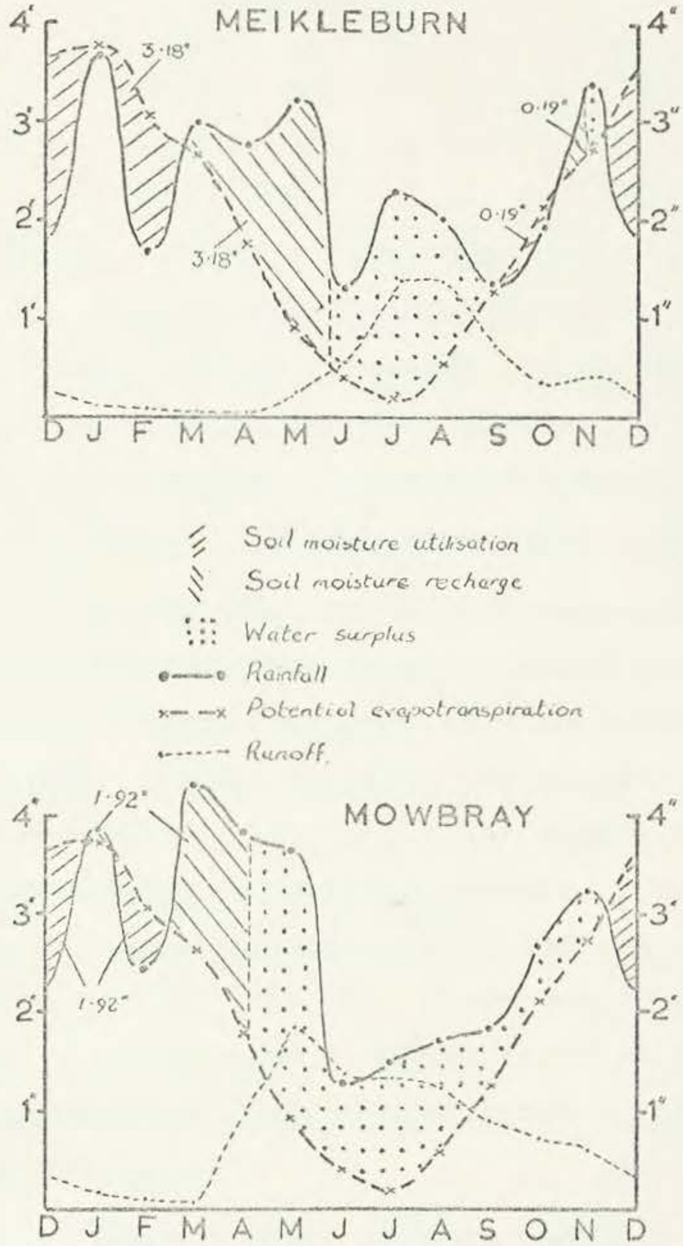


FIGURE 7 EVAPOTRANSPIRATION DIAGRAMS.

i.e.	Moisture Index	No. of Dry Months
Yellow-grey earth zone	-2.5 to 29.5 (avge 14.2)	8 (avge)
Transitional YGE - YBE	35 to 91 (avge 51)	5 (avge)
Yellow-brown earth	68 to 208 (avge 113)	1 (avge)

Comparing the data from Table 5 with these conclusions of Miss Hurst, it will be seen that Meikleburn falls into the yellow-grey earth zone, probably towards the moister end of this zone since at no time of the year is there a moisture deficiency, and Mowbray may be considered as being in the region of the yellow-grey earth to yellow-brown earth transition.

A slight discrepancy does occur when comparing the data from these two stations with the graph proposed by Miller (1958) for separating climatic stations into various soil zones and weathering sub-zones. On his diagram, the plotted positions for Meikleburn and Mowbray fall within the weakly weathering sub-zone of the yellow-brown earths. However, considering the calculated climatic types (Thornthwaite, 1948), B_1B_1'a'r for Meikleburn and B_2B_1'a'r for Mowbray, these two can be likened to other stations with the same climatic types in the yellow-grey earth and transitional yellow-grey earth to yellow-brown earth zones respectively.

As seen from Figure 5 there is a projected increase in rainfall towards the head of the catchment. In this region the soils would be expected to fall into the yellow-brown earth zone. As there would not be an anticipated rise in annual temperature, rather a decrease in annual average temperature should be encountered, annual total potential evapotranspiration (Thornthwaite, 1948, Garnier, 1951) would decrease. This means, that with this decrease in P-E, and a projected rise in moisture index, such soils occuring in this region would fall within the weakly weathering sub-zone of the yellow-brown earth zone as outlined by Miller (1958). Balanced against this deduction though, are the considerations of the lower water holding capacity of soils in the upper basin and greater runoff due to the stronger slopes.

The greater part of the rain falling in the Mowbray area is derived from cold fronts associated with southwesterly air streams which follow the passage of a high pressure system and the associated nor'wester (Garnier, 1958). Some 81% of the annual average precipitation at Meikleburn falls within groups of two or more days, obviously a result of the influence of these southwesterly air streams and their associated cold fronts. During these periods mist hangs low in the upper part of the valley and evapotranspiration is reduced to a minimum.

Snow covers the tops of the watershed down to about 4000 ft for between three and five months each year, and often extends to 3000 ft for periods totalling between two and four months per annum. Fairlie experiences 157 days of ground frost (N.Z. Meteorological Service 1966) and it is certain that the Mowbray area has at least this number if not more frosts per year. In fact frosts may be experienced at any time of the year, the months of December and January being no exception (I. H. Beattie, pers comm).

4. VEGETATION

(1) Present Vegetation

The present day vegetation of the Mowbray region falls into two broad categories. A short-tussock grassland community

Table 5 - Thornthwaite Climatic Indices for Two Stations in the Mowbray Area Assuming an Annual Temperature Range Similar to that Experienced at Lake Tekapo and at Latitude of Approximately 44° South

1. Meikleburn

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature °F	57.3	56.8	54.0	48.4	41.4	36.6	34.2	37.4	42.8	47.8	51.2	55.7	47.0
" °C	14.0	13.8	12.2	9.1	5.2	2.6	1.2	3.0	6.0	8.8	10.7	13.2	
i	4.75	4.65	3.86	2.48	1.06	0.37	0.12	0.46	1.32	2.35	3.16	4.35	I = 28.93
Unadjusted P-E cm	7.3	7.1	6.3	4.8	2.7	1.4	0.6	1.6	3.2	4.6	5.6	6.9	
Adjusted P-E in.	3.74	3.01	2.65	1.74	0.88	0.41	0.19	0.57	1.25	2.12	2.71	3.61	22.88
Rainfall in.	3.69	1.67	2.99	2.74	3.20	1.29	2.25	2.02	1.33	1.93	3.37	1.82	28.30
Storage Change in.	-0.05	-1.34	+0.34	+1.00	+2.32	0	0	0	0	-0.19	+0.66	- 1.79	
Storage in.	2.16	0.82	1.16	2.16	4.00	4.00	4.00	4.00	4.00	3.81	4.00	2.21	
Actual evap'n in.	3.74	3.01	2.65	1.74	0.88	0.41	0.19	0.57	1.25	2.12	2.71	3.61	22.88
Water deficiency in.	o	0	0	0	0	0=	0	0	0	0	0	0	
Water surplus in.	0	0	0	0	0.48	0.88	2.06	1.45	0.08	0	0.47	0	5.42
Runoff in.	0.10	0.05	0.03	0.01	0.24	0.56	1.31	1.38	0.73	0.36	0.42	0.21	5.42

P-E = 22.88 inches
Humidity Index = 5.42/22.88 = 23.7%
Aridity Index = 0
Number of dry months = 8

Moisture Index = 23.7%
Summer Concentration of Thermal Efficiency = 45.2%
Climatic Type = $B_1 B_1$'a'r

Humid, mesothermal, summer concentration of TE, little or no moisture deficiency.

2. Mowbray

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature °F	57.3	56.8	54.0	48.4	41.4	36.6	34.2	37.4	42.8	47.8	51.2	55.7	47.0
" °C	14.0	13.8	12.2	9.1	5.2	2.6	1.2	3.0	6.0	8.8	10.7	13.2	
i	4.75	4.65	3.86	2.48	1.06	0.37	0.12	0.46	1.32	2.35	3.16	4.35	I = 28.93
Unadjusted P-E cm	7.3	7.1	6.3	4.8	2.7	1.4	0.6	1.6	3.2	4.6	5.6	6.9	
Adjusted P-E in.	3.74	3.01	2.65	1.74	0.88	0.41	0.19	0.57	1.25	2.12	2.71	3.61	22.88
Rainfall in.	3.81	2.39	4.29	3.82	3.65	1.29	1.47	1.71	1.82	2.67	3.22	2.24	32.38
Storage change in.	+0.07	-0.62	+1.64	+0.28	0	0	0	0	0	0	0	-1.37	
Storage in.	2.70	2.08	3.72	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.63	
Actual evap'n in.	3.74	3.01	2.65	1.74	0.88	0.41	0.19	0.57	1.25	2.12	2.71	3.61	22.88
Water Deficiency in.	0	0	0	0	0	0	0	0	0	0	0	0	
Water surplus in.	0	0	0	1.80	2.77	0.88	1.28	1.14	0.57	0.55	0.51	0	9.50
Runoff	0.15	0.08	0.04	0.92	1.84	1.37	1.32	1.23	0.90	0.72	0.62	0.31	9.50

P-E = 22.88 inches
Humidity Index = 8.60/22.88 = 41.5%
Aridity Index = 0
Number of dry months = 4

Moisture Index = 41.5%
Summer concentration of thermal efficiency = 45.2%
Climatic Type = B_2B_1'a'r

Humid, mesothermal, summer concentration of TE, no moisture deficiency.

and a tall-tussock grassland community* (Hilgendorf 1935). These are the short-tussock grasslands of Cockayne (1928) and snow-tussock grasslands of the Tussock Grasslands Research Committee (1954).

The short-tussock grasslands of parts of South Canterbury adjacent to the Mowbray area have been described by Allan (1927), Barker (1953) and Connor (1964).

Fescue or hard tussock, (Festuca noae-zelandiae) and silver tussock, (Poa caespitosa) are the dominant species and matagouri, (Discaria toumatou) and blue tussock, (Poa colensoi) are of common occurrence. Introduced grasses, notably browntop, (Agrostis tenuis) and sweet vernal, (Anthoxanthum odoratum) are widespread throughout this community. Silver tussock is not as dominant as fescue tussock and appears, in the main, to be confined to the shallower stony soils of the flood plains or on some stony north facing slopes. Fescue tussock and matagouri on the other hand are common associates (also noted by Barker 1953) and are widespread over the dry fan surfaces, and on the dry soils over loess, or mixed loess and colluvial materials of the Sherwood and Tengawai series. Hilgendorf (1935) has indicated that silver tussock prefers the warmer more fertile soils while fescue tussock is better tolerant of less fertile soils and grows on colder sites under hardier conditions than those preferred by silver tussock. Such ecological factors would account for the much greater occurrence of fescue tussock throughout the "lowland zone" of the Mowbray area.

With increasing altitude, short-tussock grassland gives

* Ecological terminology used in this section is in accord with definitions offered by Atkinson et al (1968).

way to tall (or snow) tussock grassland on cooler, moister or less exposed sites. Barker has noted that in the Hunter Hills on east facing slopes, the transition between the two occurs at 2200 to 2400 ft above sea level. Connor (1964) suggests a transition zone between 2500 to 3500 ft above sea level and more realistically suggests that past grazing and burning, in addition to the moisture regime, has affected the position of this boundary.

In the Mowbray, the transition between the two grasslands is very strongly related to aspect. On north or northwesterly aspects the transition zone may be as high as 3100 ft while on south and southwesterly aspects it descends to 2300 ft above sea level. The average is probably in the region of 2800 ft above sea level. This transition seems to conform with the boundary between the hygrous yellow-brown earths and soils of drier character.

The tall (or snow) tussock grassland community is here considered as one entity. Molloy (1963) considered that two communities existed in the zone designated as tall tussock grassland (Hilgendorf 1935), the Danthonia flavescens association of Allan (1927). In the Mackenzie country Connor (1964) described four separate grasslands in the snow (tall) tussock grasslands. In the Mowbray area this association is characterised by Chionochloa rigida (narrow-leafed snow-tussock) Celmisia spectabilis and on steep faces and ridge crests at higher levels by C. spectabilis and Chionochloa flavescens (?) (broad-leafed snow-tussock).

In addition to these species, a small shrub and herb community seems to be associated with the snow-tussock grassland in these zones. At lower altitudes a small Hebe sp. shrub has been located, and a few occurrences of Cassinia fulvida and Podocarpus nivalis have been noted. Hoheria glabrata (mountain ribbonwood) also occurs at this altitude, and as indicated by Allan (1961), is confined to old stable screes. At higher altitudes, in locations where there is a slightly reduced snow tussock cover, Cyathodes colensoi, Helichrysum plumeum, Pimelia pseudo-Lyalli, Celmisia haastii, C. incarna and Raoulia subsericea have been identified. In moister environments, adjacent to seeps or on southern aspects Blechnum penna-marina, Rhacomitrium lanuginosum var. pruinosum and Pygmea pulvinaris have been observed. In addition, flax (Phormium tenax) was observed growing on Lookout soils and Carmichaelia sp. was found in a few places, particularly on the drier stony scree and fan soils of this zone.

In places Celmisia spectabilis becomes the dominant member of the community. This is particularly so on leeward slopes; a feature which was also noted by Molloy (1963) (Plate 5).

In addition to these two main communities, a third community of restricted distribution occurs. This is a red tussock grassland community. The dominant species is red tussock (Chionochloa rubra) and this is associated with a Carex sp. and either hard tussock or snow tussock depending upon its place of occurrence. Small patches of this community occur associated with small valley streams and in regions of hillside seeps. They may occur at any level up to about 3500 ft which is the highest recorded observation, and may be associated with either the short-tussock grassland or the snow-tussock grassland.

The yellow-grey earths and yellow-grey to yellow-brown earth intergrades are covered with plants of the short-tussock grassland community. In moister locations snow tussocks are intermingled with hard tussocks, but one can very closely relate the snow-tussock grassland - short-tussock grassland boundary to the soil boundary between the upland and high country yellow-brown earths and the drier soils.

(2) Past Vegetation

Wardle (1963) has summarised the extent of early Holocene vegetation at the height of the last ice advance with the statement, " ... exposed land surfaces in these mountains (of Canterbury and Westland) consisted mainly of unstable scree supporting only sparse vegetation. There would have been dry grassland on the Canterbury foothills ... " (page 14).

By the climatic optimum, (demonstrated by Cranwell and Von Post (1936) of between 3000 and 5000 years ago forests and grasslands would have formed a continuous cover over most of the Canterbury area, (Raeside 1948, Molloy 1964, Connor 1964, Wardle 1964) although some species would not have reached areas to which they were suited due to different rates of spread. This was particularly so in the case of Nothofogus sp. (Wardle 1963, 1964).

Consequently one can envisage a similar situation existing in the Mowbray area to that pictured by Connor (1964) for the Mackenzie Country, "... The forest probably reached an altitude of 4000 to 4500 ft and there gave way to snow-tussock grassland dominated by Chionochloa rigida ..... Within the forest zone small enclaves of both red and snow tussock grassland, while rock outcrops, river beds and recently developed fans would all support species now found in the tussock grassland ..... beside tributary streams red tussocks would flourish. A short-tussock grassland would occur on some flood plains." (page 339).

The forest in the Mowbray area was probably a podocarp dominant mixed forest similar to that found on the flanks of Mt Peel (Allan 1926). Podocarp logs identified as *Podocarpus halli* (Molloy pers comm) have been found at several sites up to 3500 ft above sea level. Charcoal from between 12" and 14" depth in seven soil profiles has also been identified as *Podocarpus sp*. It is not unreasonable to assume that small stands of beech forest (containing one species, *Nothofagus solandri var cliffortioides*), similar to that found on the southern aspect of Mt Peel (Allan 1926), also occurred on similar aspects in the Mowbray area. There is no evidence, however, to indicate an extensive cover of beech forest. In fact, evidence presented by Wardle (1963, 1964) suggests only very sporadic distribution of this forest in the Canterbury area.

Destruction of the forest by fire led to the evolution of short-tussock grassland, composed of discrete communities from within the forest or from the alpine zone. During this period the snow-tussock grassland would have migrated down from the alpine and sub-alpine zones and mixed with the evolving short-tussock grassland, extending throughout the once forested zone.

The formation of a more extensive fescue-tussock grassland took place in more recent times and has been coupled with the climatic deterioration since the climatic optimum (Cranwell and Von Post 1936). Burning and grazing, probably practiced in the Mowbray area since the 1860s has led to the replacement of much tall-tussock grassland by short-tussock grassland. In the early 1940s the tall-tussock community was lower than Tripp Pass (2200') (Cutler pers comm). Heavy grazing and continued burning in the later 19th century was probably responsible for the large extent of erosion which is evident in the headwaters of the Mowbray

(Tussock Grasslands Research Committee 1954, Connor 1964). Connor (1964) has suggested that the greater resistance of red tussock to fire has led to its patchy distribution at lower levels amongst the short-tussock grassland. He feels that as this grassland was associated with the tall-tussock grassland it indicates to a marked degree the former distribution of that grassland.

Whether the short-tussock grassland will continue to encroach onto the tall-tussock grassland in the future is a matter of conjecture. Certainly, the uniformity of height at which the transition between the two occurs and the fact that this marks a boundary between moister and drier soils, suggests that this boundary has now reached relative stability. All that is now required is the implementation of conservation measures in the sub-alpine zone to assist the regeneration and re-establishment of the community.

5. LATER QUARTERNARY HISTORY

(1) Late Burnham Times

About 16,000 - 14,000 years ago (Suggate 1965), the final advance of the Otiran glaciation was taking place. The climate was cool and dry and vegetation was sparse. Loess was blown out of the rivers on the plains and was deposited, on older weathered surfaces of the downs and plains (Raeside 1964). The snowline was possibly as low as 3500 ft (Willet 1950, Gage 1965), but this is an average figure and local conditions may have affected the snowline in several ways. In the Mowbray area, however, this would seem to be a fairly accurate estimate.

It is conceivable that during this time, loess should also be deposited in high country basins as well as over the downs and plains. Loess derived locally and possibly blown into the area from the Fairlie region to the southwest (Gage 1965 notes such prevailing wind directions p. 13) coated the hillsides, to a variable depth, up to the snowline. At elevations (and on the steeper slopes) near the snowline, periglacial conditions existed (Willet 1950) and the accumulations of loess were probably subjected to cryergic phenomena such as solifluction (Plate 21), resulting in the formation of mixed loess and colluvial debris deposits.

(2) Meikleburn Times

With the gradual warming which accompanied the emergence from the ice age, the open sub-alpine vegetation of the area was invaded by tall tussock grassland. The tussock-grassland itself giving way eventually to a dominantly podocarp forest. The appearance of podocarps was due to:

(a) their preservation in pockets on the plains during the ice advance,
(b) the almost complete removal of beech from the central South Island area during the later Pleistocene,
(c) the more rapid dispersal characteristics of the podocarps, (Cranwell and von Post 1936, Wardle 1963, 1964, Harris 1964).

At lower levels a short-tussock/tall-tussock community may have occurred in drier pockets within the forest.

With the melting of the snow and the higher runoff from the then less vegetated surface following increases in precipitation, erosion of some of the freshly deposited materials, and the older surface materials from above the old snowline, took place. This fan material was probably laid down at about the same time as the gravels of the St Bernard formation (Suggate 1965) and the finer materials of the Springston formation (Suggate 1963). Older fan gravels laid down by the Mowbray and Orari rivers during earlier inter-stadial periods were buried at this time. The later sediments encroached upon, but did not completely cover, the central Meikleburn stream area where finer deposits, due to a lower base level and reduced rates of flow, were being accumulated.

The wide spreading of forests during this warming phase, or "hypsithermal period", variously dated as from 6500 to 2500 years BP (Cranwell and von Post 1936, Harris 1963), 7500 to 6000 years BP (Cox and Mead 1963) or around 9000 years BP (Hendy and Wilson 1968), (Table 6), saw the culmination in the distribution of forests in the Mowbray area. The data obtained from pollen diagrams appears to indicate a change from podocarp dominant to beech forest over a wide time span. The dramatic appearance of the beech, considered as the beginning of a cooler period, occurred at varying times throughout the South Island (Moar pers comm). It is not unreasonable to believe that a forest imbalance, as noted in more recent times by Holloway (1954) in Southland, occurred during this change to cooler conditions. Consequently, many of the recorded dates of change, based on vegetation alone, probably antedate the actual climatic transition by some time. It would seem more realistic therefore to believe the dates of Cox and Mead or Hendy and Wilson (Table 6).

(3) Templeton Times

Following the onset of this cooler climate, there is evidence to show the occurrence of widespread natural fires over the Plains and downs area (Cox and Mead 1963) (Fergusson and Rafter 1959) (Moar pers comm), between 6000 and 6700 years BP. It is thought that fires at this time caused the destruction of the major part of the forest in the Mowbray area and led to a period of erosion and subsequent downstream aggradation over

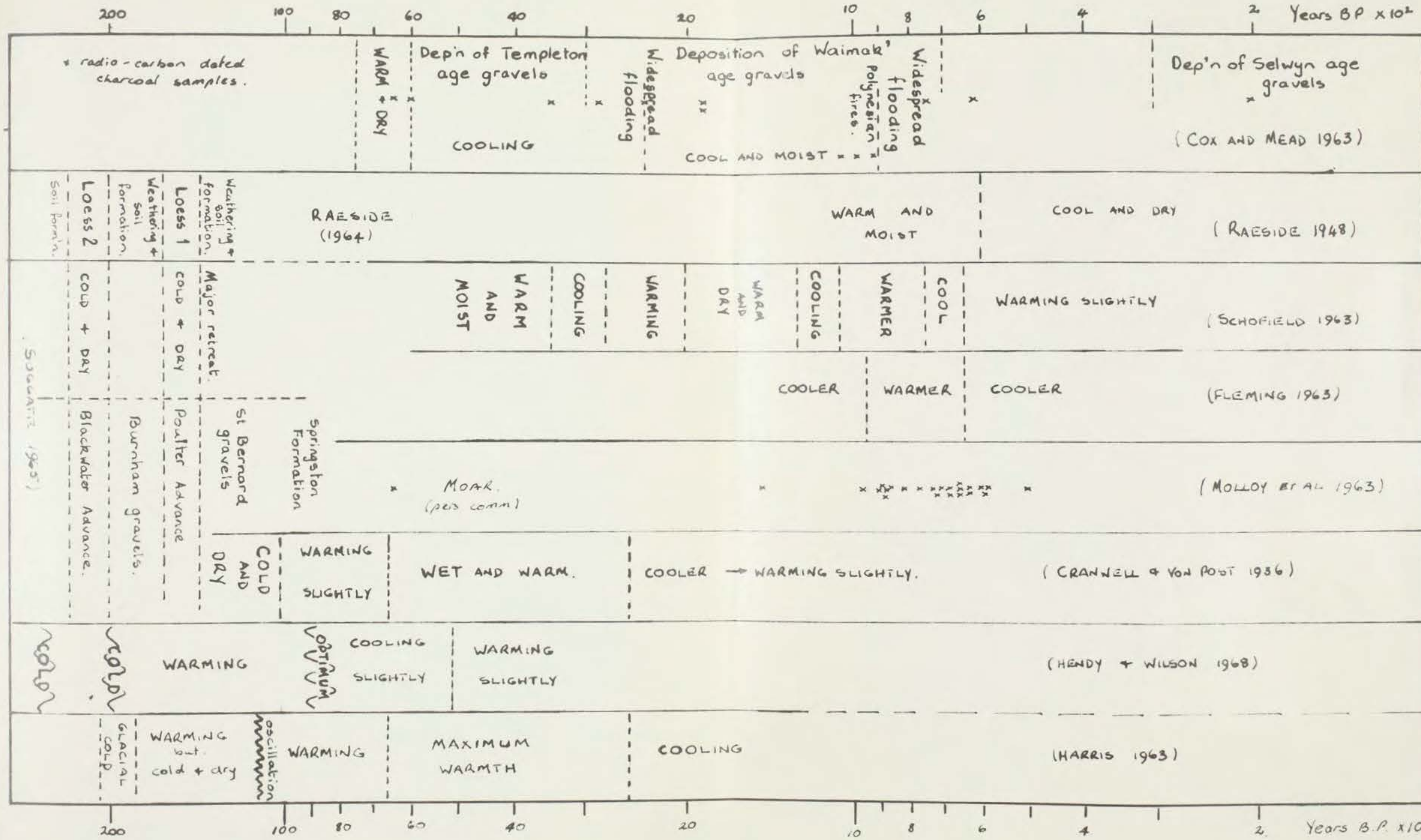


TABLE 6 VARIOUS VIEWS ON SEDIMENTATION AND CLIMATE IN THE LATE QUATERNARY.

the Mowbray and Orari and Meikleburn fans. This period of aggradation can be correlated with the deposition of gravels and loess forming the Templeton surface of Cox and Mead (1963). Loess of local origin was deposited on the eroded surfaces of the older deposits of loess, and mixed loess and solifluction deposits, of the rolling and hilly lands, and on alluvial terrace and fan surfaces.

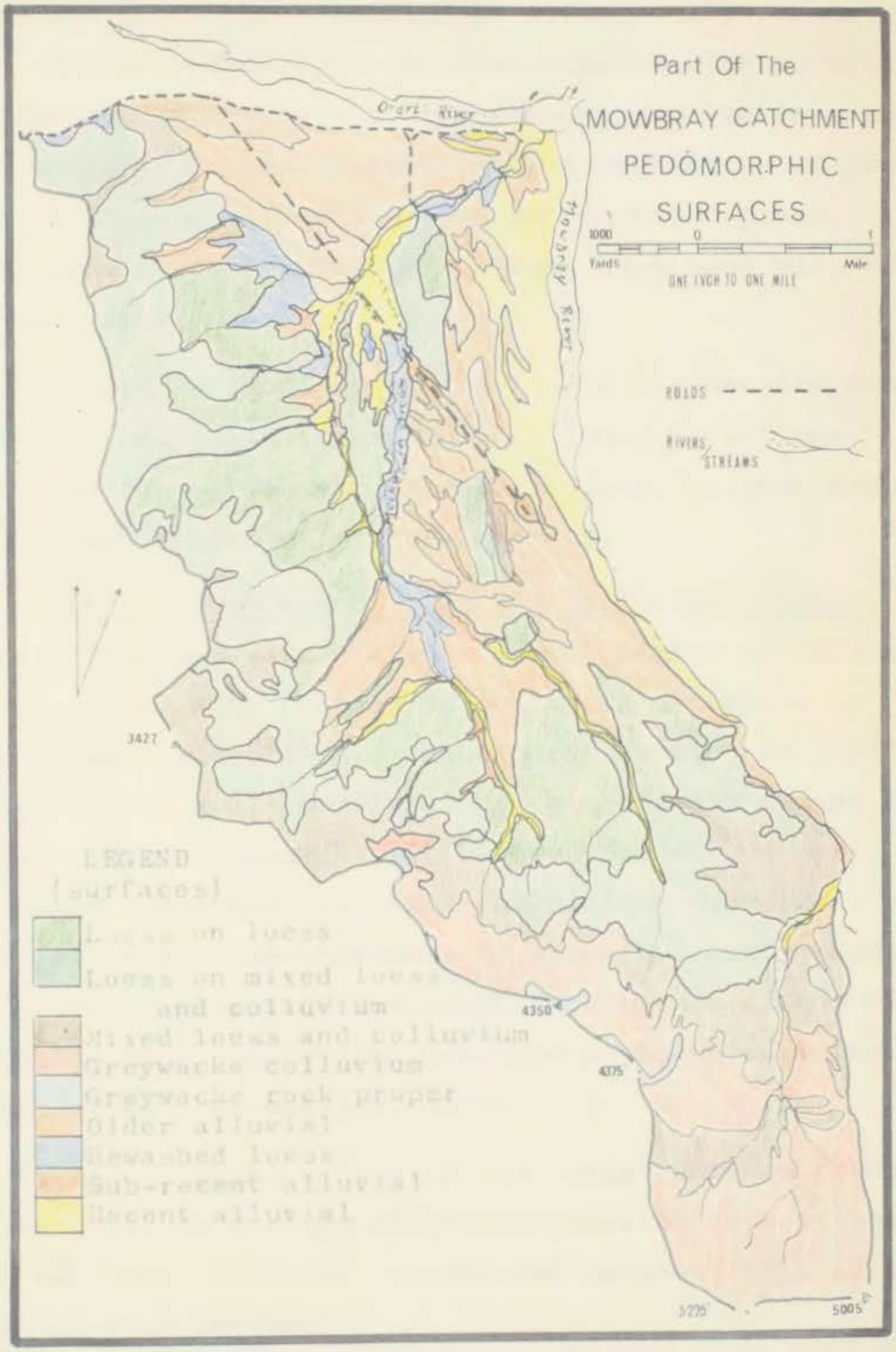
(4) Waimakariri Times

Pockets of podocarp forest still remained in some moister locations but the major part of the Mowbray was invaded by the tall-tussock grassland descending from the sub-alpine zone. Periodic burning during the ensuing period (Cox and Mead 1963, Molloy et al 1963) (Connor 1964), coupled with a period of wide-spread flooding commencing about 2500 years BP (Cox and Mead 1963) also affected the Mowbray area. At this time less extensive fan sediments were deposited on the Mowbray and Orari fans and in the upper Meikleburn area.

(5) Polynesian Times

The advent of human occupation and the widespread Polynesian burnings during a period of warmer and moister conditions are well documented (Table 6). Widespread flooding at this time gave rise to additional deposits of gravels over the Mowbray and Orari fans and along the upper course of the Meikleburn. There was a probable period of very minor accumulation of loess of local origin at this period; particularly at lower elevations on rolling and gently sloping stable fan surfaces. The few remaining pockets of podocarp forest were burnt at this stage. The few totara logs found in the Mowbray area may be correlated with the logs observed by Hardcastle (1908) and Raeside (1948) in adjacent

Fig 8



Part Of The
MOWBRAY CATCHMENT
PEDOMORPHIC
SURFACES
1000
0
1
Yards
Mile
ONE INCH TO ONE MILE
ROADS
RIVERS, STREAMS
Orari River
Mowbray River
3427
4350
4375
5225
5005
LEGEND
(surfaces)
Loess on loess
Loess on mixed loess and colluvium
Mixed loess and colluvium
Greywacke colluvium
Greywacke rock proper
Older alluvial
Rewashed loess
Sub-recent alluvial
Recent alluvial

soil formation and probably reduced the supply of loess (Raeside 1964). A period of wetting and drying cycles as outlined by Raeside (1964) led to the formation of a fragipan in these palaesols. Widespread deforestation associated with burning in the cooler period following the climatic optimum led to a period of erosion followed by the initial rapid accumulation of loess, on the eroded surface of the fragipan in Templeton times. Periodic accumulations of loess since have kept pace with erosion until the most recent times.

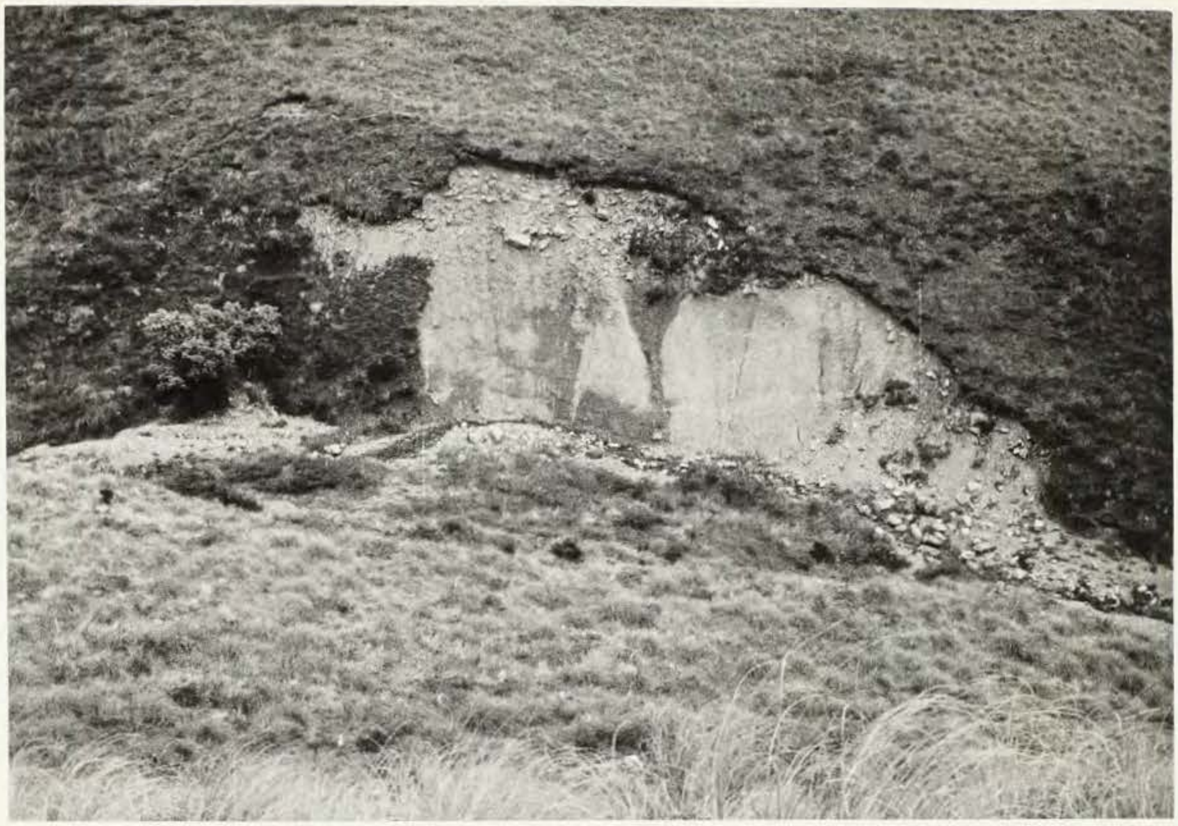
This surface is found on the rolling hillsides and near the crests of the lower hills and ridges, at lower elevations adjacent to the fan surfaces. Sherwood, Opuha, Skipton and Clayton soils are developed on this surface.

(b) <u>The "loess on mixed loess and colluvium" surface</u> - Loess deposited during late Otiran times at higher altitudes was subjected to mixing with underlying colluvial materials by cryergic phenomena (Gage 1965). Subsequent erosion following devegetation of the soils developed on this deposit during the post glacial climatic maximum left a bared surface of semi-compacted mixed loess and colluvial materials. Subsequent depositions of loess, the thickness of which was controlled by exposure, angle of slope and the length and nature of the hillside above the sites of accumulation, occurred on these surfaces in the same manner as that outlined above.

The "loess on mixed colluvium and loess" surface occurs at higher elevations, on steeper slopes and moister aspects than the "loess on loess" surface. Kakahu and Tengawai hill soils have formed on this surface.

Plate 6 - Colluvial gravels over an older deposit of mixed loess and fine colluvium on colluvium. Headwaters of the Meikleburn stream.

Plate 7 - Sub-recent terrace gravels of Templeton times overlying older colluvial fan detritus and being overwhelmed by more recent colluvial slope debris.



bring fresh material from deeper in the solum into the upper solum. Thus, the soils on this surface show the effects of strong physical and only weak chemical weathering.

The "colluvium surface" is covered with snow for short periods annually and occurs at higher elevations than the "mixed loess and colluvium" surface. Tekoa and Kaikoura soils occur on this surface, their fine earth fraction being due in a large part to deeper soil materials formed during the post glacial climatic optimum brought into the upper part of the present solum by erosion and mass movement.

(e) The "greywacke rock proper" surface - On narrow ridges above the "colluvium surface" the physical and chemical weathering of greywacke rock in place has proceeded since the end of the Otiran glaciation. Because of the narrowness of these ridge crests they have continually supplied debris to lower slope locations during periods of erosion. As a consequence the soils have remained shallow, particularly during erosive intervals. Soils of the Kaikoura series, hill phase occur on this surface.

Also included with this surface, and shown as such on Fig. 8, is the much older surface on which the Kirkliston series is developed. This surface probably dates back to the last inter-stadial, at least, (early Burnham times) as the Kirkliston series show much stronger morphological development than the Kaikoura hill soils. As it is of very limited extent, and as no firm conclusions can be drawn about its origin without extensive investigation in areas adjacent to the Mowbray catchment, it is not discussed separately. However, it is probable that at some stage it was far more extensive and formed a continuum with the "fossil" peneplain observed by Gair (1962) on Blue Mountain.

(f) The "older alluvial" surface - In the immediate post-Otiran times, rapid erosion of materials from moderately and steeply sloping hillsides occurred. This material was washed out into the lower basin of the Mowbray. These new fan deposits probably overlaid older gravels deposited during the preceding interstadial period (i.e. Burnham times). Finer sediments accumulated on the fan extremities in a similar fashion to that outlined by McCraw (1965, 1968). Subsequent fan building has left these extremities uncovered or subsequent erosion may have re-exposed these older deposits of fine texture. Coarse loess may have accumulated in places during post climatic optimum and later phases. Low ridges have been deflated by wind action thus tending to even out the surface.

This "older alluvial" surface has given rise to the soils of the Meikleburn series. Such soils exhibit better profile development and generally finer textures than the soils developed on more recent alluvium.

(g) The "rewashed loess" surface - Following the burning of the forest in the catchment at the end of the climatic optimum, increased runoff transported appreciable quantities of loess onto the floodplain of the Meikleburn stream. Fine materials eroded from the "older alluvial" surface also contributed to these deposits. The soils of the Wakanui series which covered this surface were originally seasonally poorly drained.

The lowering of the base level about 3000 years ago due to lower sea level (Schofield 1963) assisted in improving the drainage of these soils and led to the development of deeper stream channels through this surface. Accumulation of loess in recent times has taken place over this surface (see Plate 19).

(h) The "sub-recent alluvial" surface - The increased erosion following the burning of the forests after the climatic optimum also brought large amounts of detritus onto the fans of the Mowbray, Orari and Meikleburn in Templeton times. These deposits covered the coarser gravels of older alluvial surface on the central parts of the Mowbray and Orari fans. The gravels of this surface gave rise to the soils of the Mowbray series. Later deposits in Waimakariri times, on the edges of these fans and adjacent to the Mowbray river and Meikleburn stream, can be related to the lowering of base level about 3000 years ago mentioned above, and the widespread flooding of this period on the Canterbury Plains (Cox and Mead, 1963). These later deposits were peripheral to the main parts of the fans and Ashwick soils are developed on them.

In more recent times the infilling of depressions by wind deflation of adjacent slightly higher channel lines has tended to even the surface. This process has also produced a complex of slightly deeper, less stony and shallower, more stony soils.

(i) The "recent alluvial" surface - Widespread flooding, following the Polynesian fires (Cox and Mead 1963) inaugurated a renewed period of aggradation in the area. The Mowbray river was so far below the apex of its fan that the sediments were carried well downstream before they could be spread over the "sub-recent" and "older alluvial" surfaces.

In the ensuing period following the early flooding much of the fine material was blown off these deposits, accumulating on the adjacent slopes as more recent additions of loess. A renewed period of aggradation following European burning and grazing deposited gravels over this surface and adjacent to the Meikleburn stream in its upper reaches.

During the period leading up to the Polynesian fires, slow, continuous deposition of fine sediments had been taking place in a small, shallow lake adjacent to the lower course of the Meikleburn. The increased runoff following the Polynesian fires increased the erosive power of the Meikleburn and led to the drainage of this lake, exposing the sediments to sub-aerial soil formation.

All of these deposits have been grouped together as forming the "recent alluvial" surface. The well drained stony deposits of the Mowbray and Meikleburn have given rise to the Tasman soils. The poorly drained sediments adjacent to the lower Meikleburn stream have formed Taitapu soils.

Table 7 summarises the sequence of events leading up to the construction of these surfaces and the eventual formation of soils on them. In a later chapter their implications for soil genesis will be discussed and other than chronological methods of correlating the surfaces on the gently to strongly sloping surfaces will be outlined.

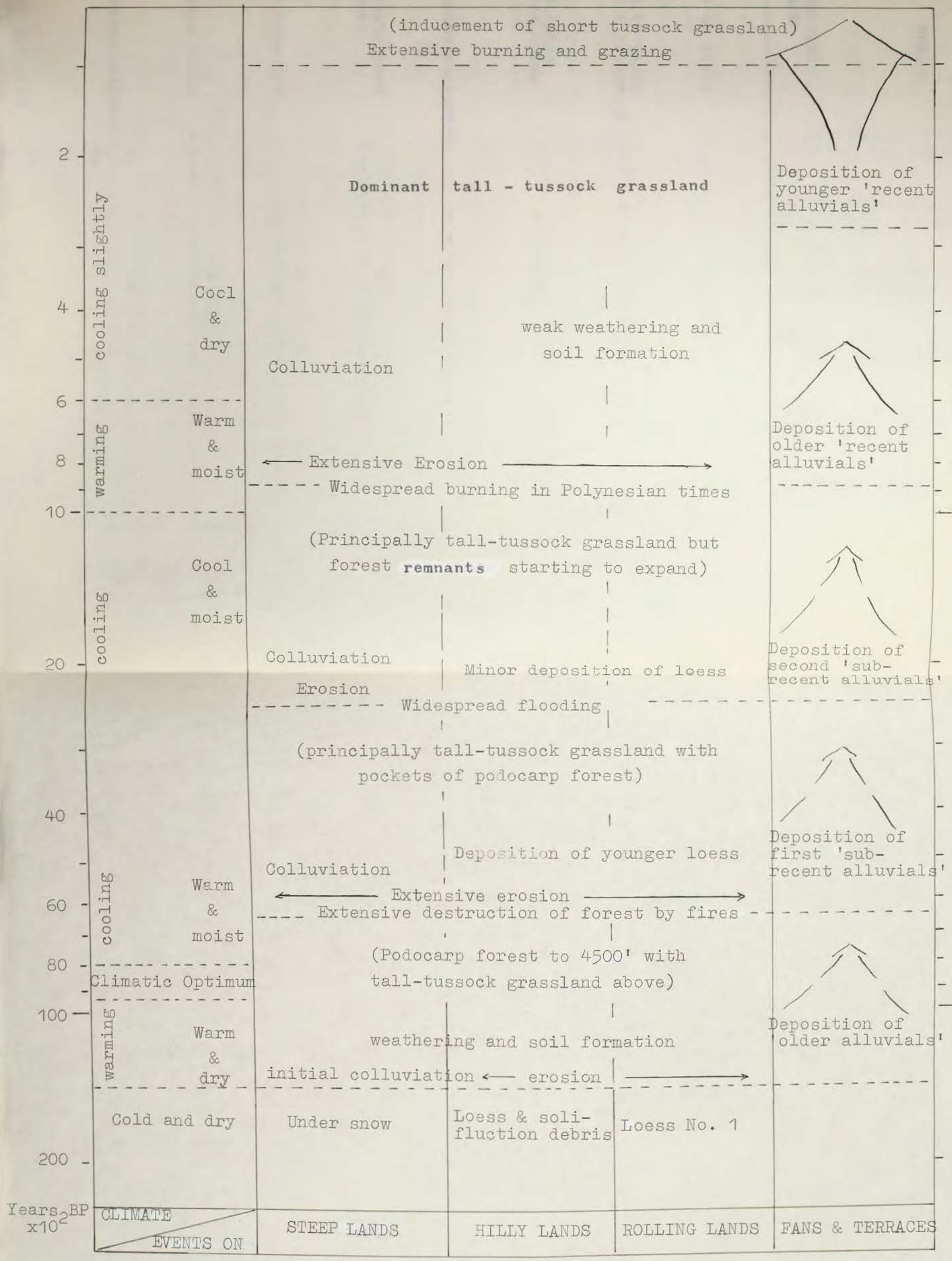


TABLE 7 SEQUENCE OF EVENTS LEADING TO THE FORMATION OF PEDOMORPHIC SURFACES IN THE MOWBRAY AREA

TABLE 8. Correlation of Pedomorphic Surfaces and Later Quarternary Events

PEDOMORPHIC SURFACE \ PERIOD	16,000-14,000 yr.BP. Late Burnham times.	14,000-7000 yrs. BP. Meikleburn times.	7000 - 2500 yrs. BP. Templeton times.	2500 - 1000 yrs. BP. Waimakariri times.	1000 - 100 yrs. BP. Polynesian times.	100 yrs.BP.-present. European times.
Loess on loess				+	+	+
Loess on mixed loess & colluvium				+	+ −	+ −
Mixed loess and colluvium				+ * −	+ * −	−
Greywacke colluvium			−	* −	* −	* −
Greywacke rock in place			+ −	−	−	−
Older alluvial			+	+ −	−	−
Rewashed loess			+	+	+	+
Subrecent alluvial 1.				−	−	−
Subrecent alluvial 2.					−	−
Recent alluvial 1.						−
Recent alluvial 2.						

——— Formation of present solum. ------ Accumulation/ deposition & weathering of underlying materials.

\+ accumulation by wind or water
\- loss by erosion
* rejuvenation by gravity accumulation or mixing.

CHAPTER V

SOILS

1. ARRANGED PHYSIOGRAPHICALLY

(1) Soils of the Floodplains, Levees and Bottomlands

Four major stages of sedimentation can be traced on the floodplains, terraces and fans of the Mowbray catchment. The first stage is considered to be post-Otiran in age, designated above as Meikleburn times. Extensive fan formation occurred in the lower basin. Terraces formed at this time in the gorge and upper basin have been almost completely removed by subsequent erosion, or buried by lateral fan aggradation (Plate 7). Subsequent fan building in the lower basin has left only the fine toe sediments exposed. Meikleburn series have developed on these deposits.

The second stage of fan and terrace formation occured in Templeton times. The coarser sediments of this period have given rise to the Mowbray series. Fine textured sediments eroded from the earlier Meikleburn age sediments on the Mowbray and Orari fans were deposited in imperfectly drained locations between these two fans. To these rewashed deposits were added sediments carried by the Meikleburn stream from the adjacent eroding watershed upland. These deposits which have probably received minor additions of rewashed material in more recent times, have given rise to the Wakanui series.

The third sedimentary phase in Waimakariri times deposited coarse alluvium on the peripheries of the established fans, and resulted in the formation of terraces in the gorge and upper basin. Coarse textured alluvium was also deposited in the upper reaches of the Meikleburn stream. Soils developed on alluvium of this age are the Ashwick series. In addition, the slow sedimentation of fine textured alluvium from the Meikleburn stream and eroding adjacent watershed upland was deposited in a poorly drained depression between the two major fans. Evidence suggests that this depression existed as a shallow lake or swamp at one time. The finer sediments deposited in this environment are the parent materials of the Taitapu series.

The final sedimentary phase followed Polynesian fires of about 900 years ago. Recent alluvium has accumulated adjacent to the Mowbray and Orari rivers and occurs as better drained deposits along the floodplain of the upper Meikleburn stream. The Tasman series is found on this recent alluvium. More recent deposition of alluvium over the last 300 years has also taken place in these locations. Quick-test analyses of Tasman series have revealed the presence of these more recent deposits but the soils developed on them have not been separated from the Tasman series. The soils developed on these more recent deposits, however, may be correlated with the Selwyn series of Cox and Mead (1963), Ward et al (1964) and Cox et al (in press).

The youngest soils derived from the alluvial deposits of the floodplains, levees and bottomlands, the Tasman series, have A/AC profiles and overlie gravels at 10" to 12". Taitapu series, found in the bottomlands, are poorly drained and have turfy topsoils which overlie wet, gleyed, incipient B horizons and gleyed C horizons. On the old levees of the Meikleburn stream, Wakanui series have had a longer period of formation than the two former series and show distinct B horizon development. Weak gley characteristics are evident in this horizon which has pale yellow or pale brownish grey colours. The underlying C horizon is more gleyed and often has a sandy clay loam texture. These three series have been respectively classified as recent soils, recent gley soils and yellow-grey earths.

(a) Tasman series

i. Described elsewhere - environmental range. Gibbs et al (1945) first described the Tasman series. They found these soils on the recent alluvial deposits of the wide valley floors of the principal rivers of the South Island high country. They said, "The soils cover the lowest terraces, and for the most part are shallow, stony, or sandy, and dry out rapidly". Later, the series was extended to the drier valleys of the upper Awatere and Clarence by Gibbs and Beggs (1953). These authors considered that their occurrence in Marlborough under 30" to 45" of rainfall was under a drier climate than elsewhere in the South Island. Soil Bureau staff (1968a) considered the Tasman soils as those on greywacke alluvium, with some thin patches of loess, under fescue and blue tussock grassland and matagouri scrub, and in receipt of between 20" and 150" of rainfall annually. They occur on flat to gently sloping flood plains and terraces and gently to moderately sloping fans between 900' and 2500' above sea level. Types included mainly shallow and stony sandy loams and silt loams, and all types were considered to be well drained.

The Tasman soils grade into and are considered to be the upland and high country counterparts of the Waimakariri soils which have been mapped in the lowland regions, adjacent to the Mowbray area, by Raeside et al (1959) and Kear et al (1967). Raeside noted that some Waimakariri soils in the Geraldine County are derived from alluvium laid down during the Orari flood of 1868. Kear et al have also noted a very youthful age for

Waimakariri soils. Cox (1962), Cox and Mead (1963), Ward et al (1964) however, have separated those soils of 300 years or younger age as Selwyn and related soils. Cox (1962) and Cox and Mead (1963) suggest that the Waimakariri soils may be much older than this, and possibly originating following initial deposition as long ago as 2,400 years BP.

The Tasman soils have not been differentiated on an age basis, but it is almost certain that both older and younger soils of the Tasman series occur in the Mowbray area. Consequently in the Mowbray area all well drained soils from recent greywacke alluvium on floodplains, levees and channels in low fans have been grouped in the Tasman series.

- Modal Profile

Because Tasman series vary widely in form, it is difficult to generalise. However, a typical profile would probably be an A horizon of 8" of very dark greyish brown very friable sandy loam with weak granular and crumb structure over a very stony, brown to olive brown sandy loam AC horizon on an olive brown or olive very stony loose coarse sand C. Textures vary from silt loams to sands in the A horizon which may or may not be stony or gravelly. Profile development is restricted to the build-up of organic matter in the topsoil.

The few published analyses of the Tasman series show their chemistry to be dependent, to a very large degree, on the nature of the alluvium. Cox (1962) notes that they are much more leached and lower in Truog and/or citric soluble phosphorus than one expects in recent soils. An analysis given by Blakemore (1962) reveals a BS % of 27% in the A horizon and 18% in the AC. The pH is 5.3 and 5.4 respectively. Table 9 compares sets of "quick-test" analyses quoted by Cox and by McFadden (1969) with two similar analyses for Tasman series in the Mowbray area. The wide range in chemistry of the Mowbray samples would tend to support the idea of older and younger soils in the Tasman series.

Table 9 - Comparison of Quick-Test Analysis of Tasman Soils

Location	Depth	pH	Ca	K	P (Truog)	P. (Bray)	
Riversdale Flats	0-4"	5.05	1	6-9	5		Cox (1962)
Mt White	0-3"	6.0	5	12	2.0		Cox (1962
Potts/ Rangitata confluence	0-3"	5.8	3	9	9.25	4	McFadden (1969)
Orari fan	0-6"	5.4	1	3-4	3	24-27)	This survey
Mowbray fan	0-6"	6.0	7	2	13-14	5-6)	This survey

ii. This Survey - environment - In the Mowbray area Tasman soils occur as silt loams, sandy silt loams, sandy loams and loamy sands with stony and very stony modification. They are on level or very gently sloping terrain, usually have boulders and stones scattered over the surface and support a short tussock community of hard, or silver and blue tussock and scattered matagouri. Raoulia sp. and native broom are common on both the younger phases and on the low ridges on the surface which are currently subjected to wind erosion. They are all derived from greywacke alluvium and are well and very well drained. It is not proposed to give profiles of all types mapped, since stony and very stony types are, except for their stoniness, similar to the parent textural type.

- Modal Profiles

The Tasman silt loam is the only type which does not have boulders and stones apparent on the surface (but they do occur in the AC horizon within 6" of the surface) and has the densest vegetative cover:

A_1	4"	very dark greyish brown; very friable silt loam with moderate to strong granular and crumb structure and rare fine gravels,
AC	5"	dark brown; very friable; very stony sandy loam with weak granular structure and many subrounded gravels to small boulders,
u(B)	on	olive brown; friable fine sandy silt loam with weak nutty structure and rare gravels.

The Tasman stony silt loam and the Tasman very stony silt loam, because of their coarser components, and possibly because of a slightly longer period during which melanisation has been taking place, have deeper A horizons than the silt loam. Otherwise they are basically the same. A Tasman stony silt loam profile:

A_{11}	7"	very dark greyish brown; very friable; slightly stony silt loam with moderate to strong granular and very fine nutty structure; common small stones,
A_{12}	6"	very dark greyish brown; very friable to loose; very stony silt loam with moderate nutty and granular structure; many sub-rounded gravels to large stones,
AC	on	dark brown; loose; very stony sandy silt loam with weak granular and crumb structure; abundant gravels and large stones.

In areas where the contribution of alluvium has been predominantly sandy or where finer material has been removed by erosion, thus concentrating sand size material amongst stones, the Tasman sandy loam and Tasman stony and very stony sandy loams occur. An example of a Tasman sandy loam of young age on a low terrace is:

A_1	9"	dark greyish brown; very friable sandy loam with very weak nutty aggregation breaking to weak granular and crumb structure,
C	on	dark brown; extremely stony coarse sand; loose and structureless with abundant gravels to small boulders of greywacke alluvium.

A profile of a Tasman stony sandy loam found on the upper Mowbray fan in areas where there appears to have been considerable wind deflation of what was originally a deeper, less stony soil is:

A_1	5"	dark greyish brown; loose, and tending to be fluffy; stony sandy loam,
AC	5"	olive brown; loose to very friable; stony sandy loam,
C	on	olive brown; very friable; very stony sandy loam.

The Tasman very stony sandy loams have very thin profiles and are generally found on lower terraces or in old flood channels.

Intermediate in texture between the Tasman silt loam and the Tasman sandy loam is the Tasman sandy silt loam (or "loam"). These soils have similar morphology to that mentioned above but appear to be derived from either the early stages of wind deflation of low ridges or the washing and mixing of fines in small previously (slightly) eroded channels on the fans and terraces. A profile illustrating the former condition is:

A_{11}	3"	very dark greyish brown; very friable; sandy silt loam with moderate granular and crumb structure,
A_{12}	2"	dark greyish brown; very friable; sandy silt loam with weak fine nutty structure; rare gravels and stones,
Ac	6"	dark brown; loose; very stony sandy loam with very weak granular and crumb; many gravels to small boulders,
C	on	brown; loose and structureless; extremely stony loamy sand.

The types which characterise the most recently accumulative Tasman series in the Mowbray area are the sandy loam on low terraces and the Tasman loamy sand, which is confined to the upper part of the Meikleburn stream. A profile of the Tasman loamy sand is:

A_1	3"	dark brown; loose; humic loamy sand with weak to moderate crumb and granular structure,
(A)C	5"	olive brown; loose; very stony sand with very weak fine crumb structure; many subrounded gravels to large stones,
C	on	olive brown; loose and structureless; stony sand.

Near the headwaters of this stream a small area of very recent Tasman loamy sand occurs. This is associated with the eroding face of an outcrop of Tertiary quartz sands and displays only a weakly melanised thin A_1 over almost pure quartz sand.

In most cases it has not been possible to map the individual types separately. This is due to the complexity of the pattern of deposition and erosion on the floodplains, terraces and fans (see Figure 11, quadrat 1, and Plates 1, 17, 18).

On the low terraces and floodplains, complexes of Tasman soils have been mapped, but on the fan surfaces, shallow Tasman soils occur in intimate association with deeper better developed soils and so have been mapped in association with such soils. The Tasman soils occurring in such associations probably result from two processes, either:

(a) rapid wind deflation of poorly vegetated low ridges, or

(b) subsequent deposition of wash material in old erosion channels following heavy rain, or late winter snow melt.

As noted above, very little is known of the chemistry of the Tasman soils and it has not been possible during this survey to enlarge on current knowledge other than with the two "quick-test" analyses cited in Table 9.

(b) Wakanui Series

i. Described elsewhere - environmental range - The Wakanui series is spread throughout the eastern parts of the South Island in depressions in low terraces and on the fringe of former coastal swamps. Typically, they are derived from greywacke alluvium and loess, and experience a rainfall of between 25" and 35". Originally, they supported a swamp vegetation and were imperfectly to poorly drained, but for the most part they have been drained and are in crops or pasture. However, during the winter months and following heavy rain, through drainage may be impeded by the heavier texture and poor permeability of the subsoil. A number of workers have identified and mapped these soils, Raeside et al (1959), Ward et al (1964), Fox et al (1964), Kear et al (1967), Cox et al (in press).

- Morphological Variability

Wakanui series vary from shallow sandy loams through sandy loams and silt loams to clay loams. Shallow silt loams, silt loams on sandy loams and sandy loams on clay loams have also been identified. The shallow Wakanui soils usually overlie greywacke alluvial gravels at between 15" and 18" depth.

Wakanui soils are distinguished by slight to distinct yellowish mottling in the subsoil. Kear et al have noted that clay loam subsoils have coarse brownish yellow and orange mottles, silt loams have diffuse orange mottles and sandy loams display reddish brown flecks. On the other hand, Ward et al (page 39) consider that when the subsoil is sandy the mottles are large and even in colour. Where the subsoils are silt loams or clay loams the mottles are small and "bright" (their word), grading from reddish brown at the centre to yellowish brown at the margins.

- Modal Profiles

Generally, Wakanui soils have deep friable dark greyish brown topsoils with moderately developed granular structure. B horizons are usually moderately or strongly mottled with matrix colours ranging from pale olive grey through pale olive brown to pale yellowish brown. This horizon is usually firm and only weakly structured. The underlying C horizon is usually very firm, massive and strongly mottled and with grey to yellow colours.

Wakanui soils are moderately acid, have medium exchange capacities and are only weakly leached. Levels of exchangeable calcium and magnesium are medium to high but potash levels are low.

ii. This survey - environment - In the Mowbray area, only two soil types have been mapped - Wakanui silt loam and Wakanui fine sandy silt loam. These soils are generally found in close association with the Meikleburn soils and occur at lower levels and in less well drained locations than these soils. On the other hand, they occur on slightly higher rises adjacent to the Taitapu soils. They are derived from fine, rewashed alluvium and resorted loess which was laid down initially at the same time and continuing to a later time than the deposition of the finer sediments of the two major fans.

The fine sandy textural influence in the upper part of the solum of some of these soils is related to more recent periods of aggradation. They originally supported a red tussock - Carex sp. association, but currently have a hard tussock - Carex sp. association on areas which have not been converted into pasture lands by oversowing with browntop, ryegrass and clover.

- Morphology

A profile of the Wakanui silt loam is:

A_1	8"	very dark greyish brown; very friable silt loam with strong granular structure tending to very fine nutty structure towards the base of the horizon; a few brown mottles line root channels at the base of the horizon,
B_{1g}	4"	grey; friable heavy silt loam with weak to moderate nutty structure; common, fine, dark yellowish brown and olive brown mottles and with rare, reddish brown mottles surrounding pores and old root channels,
(II) B_{2g}	4"	grey; friable silty clay loam with very weak coarse blocky structure tending to firm prismatic structure on drying; many, fine and medium, yellowish brown mottles and fine pale yellow patches adjacent to root channels;
(II) B_{3g}	5"	light olive grey; firm very fine sandy clay loam; structureless; many, fine and medium, vertical yellowish brown streaks,

(III)	Cg	on	light olive brown; friable, structureless sandy loam; many fine and medium vertical yellowish brown streaks.

A Wakanui shallow silt loam, with gravels at 12-14" has been observed on detailed traverses, but, as it is of only very minor extent, it has not been described or mapped separately.

The Wakanui fine sandy silt loam has been influenced to varying extents by the addition of more recent materials of fine sand size onto the surface of these soils and followed by subsequent incorporation into the profile by biological activity. An example of a fine sandy silt loam on a sandy loam is:

	A_1	8"	dark greyish brown; very friable fine sandy silt loam with moderate granular structure,
	B_1	4"	olive brown; friable fine sandy silt loam with moderate nutty structure; common, fine and medium, pale yellowish brown and yellowish brown mottles,
(II)	B_{2g}	10"	pale olive; friable sandy loam with very weak nutty structure; many, fine and medium, dark brown and yellowish brown mottles which become less distinct with depth,
(III)	C	on	pale yellow; very friable, stony loamy sand with very weak crumb-like aggregation; common subrounded greywacke gravels and stones.

Layering observed in these soils reflects a history of periodic sedimentation. On a more detailed study it is most probable that these depositional phases could be shown to closely coincide with periods of aggradation on the Orari and Mowbray fans.

There seems little evidence to support either the observations of Kear et al or Ward et al regarding the size of mottles. In sandy subsoils mottles do appear more diffuse, and on heavier subsoils they show greater colour contrast which does support Ward et al. However, heavier textured subsoils tend to have a predominance of streaky mottling, which is in accord with statements made by Kear et al. Consequently, it would appear that the nature of the mottling in the Wakanui soils is only indirectly related to the texture of the soils and may be more aptly correlated with such factors as periodicity and duration of waterlogging, and the original content of minerals or organic matter capable of releasing iron oxides for solubilisation following weathering.

(c) Taitapu Series

i. Described elsewhere - environment - Taitapu series occurs on low lying parts of valleys and flood plains. It is characterised by permanently high water tables in the undrained state and in the past it has been subjected to periodic flooding with a consequent accumulation of flood silts. The type profile (Soil Bureau Staff 1968b) is a weakly leached soil with thin solum.

- Modal Profile

The A horizon, of 10" thickness, is a very dark brown firm to friable silt loam with moderately developed granular and weakly developed nutty structure and with brown staining along the root channels near the base of the horizon. Below this is a gleyed Cg horizon which is a grey silt loam with moderately developed coarse blocky structure which breaks to fine blocks and few medium crumbs. At 20 inches this horizon intergrades to a gley horizon. The transitional Cg horizon is a grey, very moist silt loam with greenish grey vertical streaks and diffuse yellowish red mottles and has weakly developed coarse blocky structure.

- Morphology and Chemistry

Topsoil colours range from very dark greyish brown to greyish brown and pale grey, and structures are either nutty or granular. Subsoil colours range from pale brownish grey to bluish grey but almost all profiles described have either orange or greenish grey mottles, or both. The soil becomes firm and massive with depth. The principal type is the Taitapu silt loam, but shallow silt loams and sandy loams have also been reported (Raeside et al 1959, and Ward et al 1964). In addition Fitzgerald (1966) has noted the occurrence of Taitapu heavy silt loams and sandy silt loams and the Soil Bureau Staff (1968a) have recorded a range in types from clay loams to sandy loams; as have Kear et al (1967).

Taitapu series is slightly acid to near neutral, has high exchange capacity in the A horizon but low CEC lower in the profile. In a similar fashion, high levels of exchangeable cations in the A horizon decrease to low levels in the subsoil. The base saturation is very high throughout the profile.

ii. This survey - environment - In the Mowbray region Taitapu series occurs on the poorly drained floodplain of the Meikleburn stream, and in the broad bottoms of some small valleys adjacent to this floodplain. These soils are poorly and very poorly drained; although to the southwest of Kirke's road they have been artificially drained to some extent. In uncultivated locations this series usually supports a swamp vegetation of red tussock and rushes. In undrained locations, the water table varies between the surface and 12", while in drained locations the water level is usually depressed to 18" to 20".

- Morphology

These soils vary somewhat in their morphology, particularly in the thickness and organic content of the A horizon (see Quadrat 2, Fig. 12). In a few places, particularly in shallow depressions adjacent to old narrow stream channels, a moderately deep £usually less than 12") turfy, organic A horizon may be seen. Occasionally, unweathered greywacke gravel and stones are encountered below 12"-14". In all cases the A horizons are very strongly root bound with a distinct root mat at the surface.

Taitapu series generally has an A horizon of up to 10" dark grey, friable (plastic and slightly sticky when wet) silt loam, which has moderate granular structure in the upper part giving way to moderate to strong fine nutty structure with depth. Yellowish red mottles commonly line root channels and aestivation channels are frequently filled with light coloured material from lower horizons. The A horizon has an irregular boundary with a thin , incipient B horizon, which is generally a grey or greenish grey, plastic and sticky, silt loam or heavy silt loam. This horizon has many yellow, yellowish brown and orange mottles and has weak medium nutty or blocky structure. This horizon in turn lies on a Cg or CG horizon which is either grey or greenish grey in colour with varying proportions of mottling in yellowish brown, light grey and orange. Consistence and texture varies from very firm, silty clay loams to firm, sandy clay loams and this horizon is either massive and structureless or displays weak blocky structure. On drying following drainage, the subsoils show very weak prismatic structure. Although only one type has been mapped, slightly lighter textured profiles have been observed in very narrow stream channels slightly incised into this surface (see Fig. 12), and in a few places there is a very thin cover of recently contributed flood gravels and sands. A typical profile of the Taitapu silt loam is:

A_1	7"	dark grey; friable silt loam with moderate granular structure giving way to moderate to strong very fine and fine nutty structure with depth; with common, pale yellow and light greyish brown mottles and reddish brown coatings in root channels,
(B)g	5"	greenish grey and yellowish brown; friable to firm, heavy silt loam with moderate nutty structure; common, grey clay-skins lining vertical old root channels,
(II) CG	on	greenish grey and brownish yellow; friable to firm, massive silty clay loam with very weak blocky structure; common grey clay-skins in channels. Seepage water level at 12".

Those soils on the Meikleburn flood plain which have been affected by recent attempts at drainage occur adjacent to Meikleburn and Wakanui soils. A profile from this environment is:

A_1	7"	dark grey; friable silt loam with moderate granular structure becoming moderate to strong fine and very fine nutty structure with depth; yellowish red stains along root channels and some light grey mottles towards the base of the horizon,
AB(g)	3"	grey; friable sandy silt loam with moderate to strong nutty structure; many pale yellow and grey mottles,
(II) (B)g	4"	greenish grey; friable sandy silt loam with weak to moderate nutty structure; many pale yellow and brownish yellow mottles,
(III) CG_1	4"	greenish grey; friable sandy clay loam with weak coarse nutty structure tending to firm weak medium prisms; light grey and yellowish brown mottles,

(III) CG_2 on light grey; very firm, heavy silt loam; massive; common yellowish brown mottles and rare very fine manganese nodules.

The Taitapu soils of the Mowbray area show slightly better profile differentiation than the Taitapu soils of the type location (Soil Bureau Staff 1968b), or those described by other workers (see references above), and as such may be slightly older. Currently, the Meikleburn stream is eroding into its bed in the regions where this soil is mapped, and the present alluvium of this stream is gravels and sands rather than silts. However, it is conjectural whether this apparent change in the character of the Meikleburn is a result of a change in base level, or is due to greater runoff facilitated by artificial drainage.

(2) Soils of the Terraces and Younger Fans

These are soils of the Orari and Mowbray fans and the mid-reaches of the Meikleburn fan. They can be traced upstream from the fan surfaces to terraces adjacent to the Mowbray river and the Meikleburn stream. Periodic deposits of greywacke alluvial gravels during post glacial times, with related accumulation of windblown and/or water resorted loess in places form the parent material of these soils. The events leading up to the aggradation of the fans and terraces on which these soils are formed have been outlined in preceding sections.

Wind deflation of low rises and sheet erosion of surface fines into adjacent channels and depressions has tended to level and subdue the outwash pattern. As a consequence the older surfaces have a more uniform appearance than the younger deposits, which show a complex pattern of old shallow stream channels and low interfluves. The variable nature of the alluvial gravels and subsequent erosion are the factors which have determined the variations in soil type on these surfaces. Recent thin depositions of loess, however, have masked these differences in some places.

Meikleburn, Mowbray and Ashwick series can be readily differentiated on a developmental basis. Ashwick series have a very shallow A horizon overlying a transitional horizon to a stony incipient B horizon which occurs between 6" and 9" depth. This in turn gives way to a C horizon dominated by gravels and stones which in places have been cemented by vertically and laterally leached iron oxides. These soils have an A / AB / BC / C horizonation.

Mowbray series have a similar appearance but show better development in the B horizon, which is invariably stony, and occurs between 10" and 12" depth. Underlying gravels show no evidence of compaction or cementation. These soils have an A / AB / B / BC or C horizonation. By contrast, the finer sediments forming the Meikleburn series show much greater profile development. A distinct colour B_2 horizon of 6" to 12" thickness is present, and stones are rarely encountered above the BC horizon at between 16" and 20" depth.

Meikleburn soils have been classified as yellow-grey earth to yellow-brown earth intergrades and Ashwick and Mowbray soils are considered to be shallow and stony soils related to this grouping.

(a) <u>Ashwick Series</u>

i. <u>Discussed elsewhere - environment</u> - Ashwick series was first described in Kear et al (1967). It is the youngest of the three soils mapped on the low-level fans and is developed over stony and bouldery greywacke fan alluvium.

The soils of this series have a thin veneer of loess in places but Kear et al (1967) note that generally they are shallow and stony, and are very well drained. They occur on flat to very gently undulating surfaces between 900 ft and 2000 ft above sea level.

- Modal Profile

The type profile, given by Kear et al (p. 89 and also p. 36 of Soil Bureau Staff 1968a) has a very dark greyish brown friable silt loam with strongly developed granular structure and scattered boulders giving way below 8" to a yellow friable stony silt loam with weak nutty structure. The C horizon below 17" is formed of compact greywacke gravels.

A medial analysis, based on five profiles, reveals moderately acid, strongly leached soil with medium exchange capacity and medium to low levels of exchangeable cations.

ii. This survey - environment - In the Mowbray area, Ashwick series tends to be less stony and bouldery than at the type location in the Fairlie basin. This could be due to slightly greater accumulation of both wind-blown and surface washed fines than elsewhere, and lower susceptibility to wind erosion due to less intensive agricultural practices. The occurrence of this soil on smaller fans than in the Fairlie basin could also be significant. On the Mowbray and Orari fans the association of this series with the Mowbray and Meikleburn series may derive from a combination of erosion of parts of those older soils with contemporaneous deposition of wind-borne and rewashed fines. In addition, the Ashwick series is found on the next higher terrace above the Tasman series, adjacent to the Mowbray and Orari rivers and upper Meikleburn stream. They are also found on small valley (low-angle) fans overlying older terrace deposits (Profile MC 82 in Appendix 1).

The Ashwick series generally supports a poor pasture of predominantly browntop with scattered matagouri. The soils are very well drained and stones are rarely seen on the surface although rare stones may be seen in the A horizons of some profiles.

- Morphology

Soils grouped as Ashwick series in the Mowbray area display only weak profile development and have an A_1 / AB / BC horizonation. Depth to C horizon or an underlying buried profile varies from 11" to 20" and the underlying substrata is usually compact. About 6" of very dark greyish brown, very friable fine sandy silt loam or gritty silt loam with moderately to strongly developed granular and some crumb structure, overlies a thin transitional brown coloured horizon with weakly to moderately developed granular structure. Below 9" a BC horizon of olive brown to light yellowish brown friable silt loam to sandy loam, commonly stony, with weak crumb and nutty structure, occurs. The underlying C horizon is usually a compact stony coarse sand, but in some cases may be a yellowish brown or light yellowish brown stone free silt loam B horizon of a buried, older soil.

Four soil types have been recognised, but in many cases it has proved difficult to map the true extent of each. And although a homogeneous soil unit may be shown on the map, up to 50% of related Ashwick types may occur within the demarked boundaries. Profile Mc 82 (Appendix 1) is an example of the Ashwick silt loam as it occurs over an older buried soil. The profile may be abbreviated as:

A_1	6"	dark greyish brown (slightly dry); very friable gritty silt loam with strong granular structure; rare small stones,

BA	2"	yellowish brown (slightly dry); friable, slightly gritty silt loam with strong granular and moderate to weak nutty structures; few stones and gravels,
BC	3"	yellowish brown; friable, slightly gritty stony silt loam, with moderate to strong granular and weak to moderate nutty structure; common stones,
uB_2	on	light yellowish brown; friable, gritty heavy silt loam with weak nutty structure breaking to moderate to strong granular structure; few moderately to strongly weathered stones.

The Ashwick fine sandy silt loam is the most widespread of the Ashwick soils in the area. It tends to be stonier and thinner than the Ashwick silt loam and probably results from the wind erosion of fines from the surface of initially deeper soils. A typical profile is:

A_1	5"	very dark greyish brown; very friable, fine sandy silt loam with weak to moderate granular structure tending to nutty structure with depth,
BA	3"	olive brown; very friable, stony silt loam with weak crumb structure; many greywacke gravels and stones,
BC	4"	olive brown; very friable, very stony sandy silt loam with very weak crumb structure; many greywacke gravels and stones,
C	on	brown; moderately compact, moderately cemented, extremely stony coarse sand; cementing material is dark reddish brown in colour and many stones have similarly coloured stains on their under surfaces.

Soils grouped as Ashwick fine sandy loam and sandy loam tend to be alluvial accumulative soils rather than deriving their character either from recent thin accumulation of loess or deflation of existing deeper soils. They are found in the upper parts of the Meikleburn stream and in the Mowbray gorge. A profile of the Ashwick fine sandy loam is:

A_1	12"	very dark greyish brown; very friable, fine sandy loam with moderate to strong granular structure and some weak nutty structure appearing with depth,
AB	4"	olive brown; very friable, gritty fine sandy loam with strong granular structure,
BC	4"	light olive brown; very friable, stony fine sandy loam with moderate granular structure; common greywacke gravels and small stones,
uB_2	on	light yellowish brown; friable, heavy silt loam with moderately developed nutty structure.

The Ashwick sandy loam is essentially similar in morphology. The principal difference is the increase in the coarse component which is a local sedimentary effect. A profile is:

A_1	6"	very dark greyish brown; very friable sandy loam,
AB	5"	dark brown; very friable sandy loam; with a very broad irregular boundary to
BC	6"	light yellowish brown; friable sandy loam with very weak nutty structure,
C	on	light yellowish brown, very stony sand.

It can be seen from the foregoing that the soils grouped herein as Ashwick series, while displaying a similarity of basic morphology may be two separate and different units. In fact, the compact and cemented subsoil usually found under the silt loam and fine sandy silt loam types is a probable indicator of a probable greater age of these two types. The Ashwick silt loam and sandy silt loam resulting from the wind deflation of what were once much deeper and apparently better developed soils.

Apart from the similarity of morphology, however, their occurrence on the fans and terraces at levels below those of the Mowbray and Meikleburn series; or in the case of the profiles displaying buried horizons, overlying partial soils similar to the Mowbray and Meikleburn series; is a strong unifying characteristic. No doubt a detailed investigation of their chemistry, especially in relation to iron movement, could aid in a more accurate assessment of their origin and history. And although Claridge (1961) hesitates to confirm or deny the usefulness of iron as an indicator of weathering in soils derived from greywacke it would seem that the cementation of the underlying gravels and the red stains on stones at that level is almost certainly a result of iron mobilisation.

(b) Mowbray Series - environment

This is a new series, proposed during this survey to encompass soils of moderate profile development on old alluvial fan and terrace gravels of the Mowbray, Orari and Meikleburn fan systems. On a previous survey they have been grouped with the Ashwick series (Fig. 2 - Soil Bureau Staff 1968a). It is conceivable that these soils are in fact closely related to the Ashwick soils, but it has been decided to identify and map them separately because of:

i. their occurrence on terraces ab ove those occupied by soils identified as Ashwick series,

ii. their occurrence on terraces being overwhelmed by low angle fans which exhibit soils correlated as Ashwick series, and

iii. the apparent greater degree of profile development shown by these soils in relation to Tasman and Ashwick series.

The Meikleburn soils occur on older surfaces again and may be differentiated from Mowbray series, using the same criteria used to differentiate the Ashwick and Mowbray series. The Ruapuna series does have a number of similarities with the Mowbray series. The Mowbray series, however, does not show the same intensity of colour development in the B horizon as the Ruapuna series nor is it characterised by a compact C horizon. Also, in the absence of adequate chemical data it was decided that the tentative proposal of two new series (i.e. the Mowbray and Meikleburn series) would be more satisfactory than an attempt to widen the range of established, sketchily defined sets (Soil Bureau Staff 1968a) and types (Kear et al 1967).

Mowbray series occurs on the low-level fans of the Orari and Mowbray rivers, on some low angle fans of the surrounding rolling hillsides and on terraces in the upper part of the Mowbray river. They overlie coarse greywacke fan and terrace alluvial gravels and in places have accumulations of wind-blown fines. These soils support a discontinuous short tussock (hard tussock - silver tussock) association with scattered matagouri appearing on the stonier soils and snow tussock occurring at higher altitudes. The soils receive between 28" and 35" of rain per year and are found between 1750 ft and 2700 ft elevation. They are free draining and in places stones are seen scattered over the surface.

- Morphology

In contrast with the Ashwick series, the Mowbray series displays slightly better profile development and has an A / AB / B / BC horizon sequence. B and BC horizons are almost invariably stony and rarely have colours stronger than olive brown, or yellowish brown (10 YR 5/4) in the case of the Mowbray stony silt loam. A horizons are very dark greyish brown, very friable and have moderately developed granular structure. Weakly developed nutty structure appears with depth and textures are commonly gritty. Two soil types have been recognised. A typical profile of the Mowbray silt loam is:

A_1	6"	very dark greyish brown; very friable silt loam with moderate granular and weak crumb structure,
AB	4"	brown; friable silt loam with moderate to strong fine nutty structure; rare subangular large greywacke stones,
B	6"	olive brown; friable, stony, gritty silt loam with moderate fine nutty and granular structure; common subangular and rounded greywacke gravels to large stones,
BC	on	olive brown; friable, very stony, gritty silt loam with weak crumb structure; many subangular and rounded greywacke gravels to large stones.

By contrast the Mowbray stony silt loam usually displays lighter colours in the B horizon and averages only about 11" to the base of the B horizon. A profile is:

A_1	3"	very dark greyish brown; very friable, slightly stony silt loam with weak to moderate granular and some crumb structure; few subangular greywacke gravels,

AB	3"	brown; very friable, slightly stony silt loam with moderate fine nutty and moderate to strong granular structure; few subangular greywacke gravels,
B	4"	yellowish brown; friable, stony, gritty silt loam with moderate fine nutty structure; common subangular greywacke gravels and stones,
BC	on	olive brown; very friable, very stony, fine sandy silt loam with very weak granular structure; many subangular greywacke gravels and large stones.

It is probable that the Mowbray stony silt loam has been derived from the wind or sheet erosion (depending upon angle of slope of the fan surface) of a much deeper soil - possibly the Mowbray silt loam. Wind deflation appears to have been a common process on the fans in the Mowbray catchment and complications arise therefore if depth to gravels is used as the main criterion differentiating series.

(c) Meikleburn Series - environment and related series

These soils are derived from the oldest and generally finest fan deposits. On the Mowbray fan in particular, they are found in the classical toe locations as island remnants (McCraw 1968). On the Orari fan, their occurrence, especially in association with younger soils of various ages, is a little more difficult to reconcile with the current ideas on fan building of McCraw (1968), although Carryer (1966) has suggested a mechanism for the preservation of older sediments towards the apices of fans. His explanation, however, takes no account of the size distribution of sediments through a fan depositional sequence.

The surfaces on which the Meikleburn series is developed can be separated from the surfaces of the Mowbray series by their generally more level appearance with a more continuous cover of short tussock grassland and with introduced grasses (notably browntop) on improved sites. Basically Meikleburn series has the same environmental range as the Mowbray series. Terraces of equivalent age are absent in the gorge and upper basin and consequently suggest a reduced upper altitudinal limit of 2400 ft for this series.

Meikleburn profiles are better developed, showing a colour B horizon of 9" - 12" thickness, and the base of this horizon extends to 17" to 21" depth. Rare gravels may occur in the B horizon but generally stones are not encountered until the BC or C horizons are reached. An A_1 / AB / (B_1) / B_2 / BC / C horizonation is apparent. Sherwood series which is also found on the lower fan of the Meikleburn, in association with soils of the Meikleburn series, usually has paler colours and firmer consistence in the subsoil, heavier textures throughout, and a compact BC or C horizon.

- Morphology

Meikleburn series has a dark greyish brown A horizon which is a very friable sandy silt loam with moderately to strongly developed granular structure. Below 9" to 10" the B horizon may be yellowish brown, light yellowish brown or rarely pale olive in colour, textures range from heavy silt loams to sandy clay loams and friable, weakly to moderately developed nutty structures predominate. Beneath the B horizon there may be a transitional BC horizon to a very stony weakly structured sandy loam or sandy clay loam representing a C horizon. In some cases a buried soil underlies the BC horizon.

Two soil types have been recognised. A profile of the Meikleburn silt loam is:

A_1	7"	very dark greyish brown; friable silt loam with moderately developed nutty structure,
AB/B_1	4"	light olive brown; friable silt loam with weak nutty structure,
B_2	6"	light yellowish brown; friable fine sandy clay loam with weak nutty structure,
BC	7"	light yellowish brown; very friable, stony fine sandy clay loam with weak fine nutty structure; common subrounded greywacke gravels and stones,
C	on	light yellowish brown; very friable, very stony sandy loam with weak fine crumb structure; many subrounded greywacke gravels and stones.

In places this type overlies part of an older soil. Such a profile is:

A_1	6"	very dark greyish brown; very friable silt loam with strong granular and very fine nutty structure,
AB	3"	dark greyish brown; friable silt loam with moderate to strong nutty and granular structure,
B_2	12"	olive; friable heavy silt loam with weak nutty structure; few subrounded greywacke gravels,
BC	4"	pale olive; firm, very stony, heavy silt loam with weak nutty structure; many subrounded greywacke gravels and stones,
u(B)	on	light olive brown; very friable, slightly stony silt loam with very weak nutty structure, few rounded and subrounded greywacke gravels and stones.

The detail of the survey has not allowed a positive identification of the underlying soil as a surface mapping unit.

It is quite possible though that such an older soil may occur sporadically in places mapped as Meikleburn series.

The Meikleburn sandy silt loam has a similar morphological range to that of the Meikleburn silt loam, the principle difference being the lighter textures of the topsoil; probably a sedimentation phenomena associated with the deposition of the parent materials. A profile is:

A_1	6"	very dark greyish brown; very friable sandy silt loam with moderate to strong granular and nutty structure,
AB	2"	dark greyish brown; friable silt loam with strong nutty and granular structure,
B_2	11"	light yellowish brown; friable to firm, heavy silt loam with moderate nutty structure; rare subrounded gravels; common, fine, grey vertical streaks towards base of the horizon,
C_1	7"	pale brown; firm, stony sandy clay loam with weak medium prismatic structure breaking to coarse blocky; many light grey streaks; common subrounded gravels,
(II) C_2	on	pale yellow; firm, very stony loamy gravels

Time precluded a detailed examination of the chemistry and mineralogy of the soils on fans, terraces and floodplains. It was possible, however, to obtain "quick-text" analyses of the 0-6" level of selected soils. These results are appended (Appendix 2) but do little to show conclusive differentiation between the well drained fan and floodplain soils. The imperfectly and poorly drained Wakanui and Taitapu series can be separated from the well drained soils, however, by their higher pH and Ca levels and lower levels of Bray-P.

(3) Soils of the Older Fans and Rolling Hillsides (including related hill soils)

The formation and development of the soils of the older fans and rolling hillsides is directly related to periodic deposition of loess during late Pleistocene and post glacial times. Raeside (1964) has proposed a sequence of deposition of loess beds during the later Pleistocene and early Holocene. It is assumed that a similar sequence of events occurred in the Mowbray area but, due to the much smaller source of loess, compared with that contributing loess for deposition on the Canterbury Plains and downs (Raeside 1964), these earlier depositions were essentially thin. Erosion during the period between the Waimaungan and Otiran glaciations (Chappel 1968) removed these earlier, thin, loessial deposits. Subsequent depositions of loess during the Otiran glaciation probably suffered the same fate, to a lesser or greater extent.

For the most part the soils on older fans and rolling hill-sides are derived from a thin loess deposit which appears to rest on an older loess or soil, the upper parts of which may have been removed prior to the later loessial accumulation. The older loess deposit generally occurs in the position of a C horizon in the present soils. On some terrain types, particularly those of the Kakahu hill and Tengawai hill soils, mixed loess and colluvial materials occur in the position of a C horizon and may indicate either:

i. that older loess was deposited on such slopes at a time when active solifluction was occurring. Sub-sequent erosion did not completely remove these mixed deposits and later loess accumulated on these sites at a time when solifluction was not active; or

ii. that the whole mantle represents a relatively continuous period of loess deposition. The accumulation occurring at a faster rate than the agencies of the drift regime were able to effect complete mixing with underlying colluvial debris. The blanket of loess gradually induced stability preventing further mixing.

Because of the general absence of solifluction deposits in horizons above the BC horizon in these soils, and distinctive chemical and mineralogical contrasts between B and C horizons, the former hypothesis is favoured.

Soils derived from loess have moderately deep A horizons which are dominated by strong granular structures, silt loam textures and an irregular merging boundary with the B horizons. The B horizons of these soils have slightly heavier textures, light yellowish brown varying to pale olive brown or pale yellow colours and moderately or weakly developed nutty structure. They commonly exhibit weak coarse prismatic structure towards the bottom of the solum. The underlying loess horizon is yellowish brown to light yellowish brown in colour, has a slightly coarser texture, is usually moderately compact and brown clayskins line channels and pores. In some places weak gammation is found and may extend upwards into the B horizon.

Four soils were mapped on loess on these landscapes. Those on well drained, exposed sites range from Kakahu at the highest altitudes, formed from loess over mixed loess and colluvial materials, through Sherwood formed over loess on the driest sites, to Opuha series at lower altitudes on more sheltered aspects. Moisture conditions for this group are at an optimum in the slighter coarser textured Kakahu series. As rainfall

decreasing/
decreases with altitude, the effects of drier conditions are apparent in the Sherwood series which occur on exposed shedding sites. These effects are less noticeable in the Opuha series which are found on less exposed, more normal sites. Associated soils on water cumulative (and slope-wash cumulative) sites are the Skipton and Clayton series. These series may be distinguished from the Kakahu, Sherwood and Opuha series by their heavier textured, moderately (Skipton) and strongly (Clayton) mottled pale subsoils. The relationship between these soils, and differentiating criteria are illustrated in Figures 17 and 18.

Sherwood and Opuha soils are classified as yellow-grey earths. Skipton, Kakahu and Clayton soils, because of better drainage, yet a lesser likelihood to dry out during seasonal drought and a greater degree of weathering, have been grouped with the yellow-grey to yellow-brown earths intergrade.

The yellow-grey earths have moderate to high levels of illite, interlayered hydrous micas and moderate amounts of clay-vermiculite (1). Slightly greater amounts of secondary chlorite, and clay-vermiculite (2), the latter at the expense of illite, characterise the yellow-grey to yellow-brown earth intergrades. This distinction conforms closely with the pattern determined, by Fieldes in Soil Bureau Staff (1968b).

(a) Sherwood Series

i. Described elsewhere - environmental range, morphology and chemistry

This series occurs over coarse loess, presumably of greywacke origin, on terrain ranging from very gently undulating to hilly between 1500 and 2000 ft above sea level and experiencing about 31" of rain annually (Kear et al 1967). The few adequate descriptions available show a profile with about 8" of friable, strong nutty silt loam A horizon over a pale yellowish brown, friable, heavy silt loam B horizon with only weakly developed fine nutty structure giving way below 20" to a pale yellow, very firm and massive, silty clay loam. Brown and yellowish red mottles may occur throughout the profile, but are not considered as a diagnostic criterion.

The soil is strongly acid (Metson 1961 p. 168) with low base saturation, low levels of phosphorus and exchangeable bases, except for potassium, which has medium values. The cation exchange capacities and carbon/nitrogen ratios also have medium values.

ii. <u>This survey - environment</u> - Within the Mowbray area soils of the Sherwood series occur on a range of terrain and landform types with slopes ranging from almost level to strongly sloping, and up to 2500 ft above sea level. They occur in conformity with the climatic range proposed by Kear et al (1967). They are found on almost level to very gently undulating fan surfaces over resorted loess, sometimes with gravels in the lower part of the profile. On rolling and moderately steep hillsides they occur on convex hillslopes where the youngest loess layer is moderately thick. In the uncultivated areas these soils support a short/hard tussock - browntop sward, with scattered matagouri. The free drainage through the upper part of the profile is somewhat impeded lower in the soil by the compact and massive BC and C horizons which occur at between 18 and 24" depth.

- <u>Morphology</u>

Sherwood series shows A_1 / AB / B_2 / BC / C or D horizonation. A very dark greyish brown silt loam A horizon gives way, through about 3" of transitional horizon to well developed, light yellowish brown, heavy silt loam B horizon which has firm, moderately developed nutty aggregates. The underlying BC horizon has only weakly developed, often blocky structure, usually mottled brownish yellow and/or light grey. Textures range from heavy silt loams to sandy clay loams. The C horizon (or more correctly D horizon if it is an older loess layer not contributing to the present soil) varies in colour from yellowish brown to light yellowish brown and in textures from silt loams to sandy clay loams. Weak prismatic structure associated with gammate cracks may extend upwards from this horizon through the BC into the base of the B horizon. Thin brown clayskins are common in pores in the C and/or D horizons.

Found over a variety of terrain types, the Sherwood series has been mapped in the Mowbray catchment as the Sherwood silt loam and the Sherwood silt loam - hill phase. On the lower parts of the Meikleburn, adjacent to small tributaries draining the watershed upland is an extensive area of Sherwood silt loam on almost level terrain. A profile is:

A_1	8"	very dark greyish brown; very friable silt loam with moderately developed fine nutty and granular structure,
B_2	9"	light yellowish brown; friable silt loam with moderately developed medium and fine nutty and blocky structure,
B_3	5"	yellowish brown; firm, heavy silt loam with weak blocky structure; many light grey and light yellowish brown mottles,
C	on	yellowish brown; compact and massive, silty clay loam; thin brown and light brownish grey clay coatings in some channels and pores; giving way to silty gravels below 42".

On hillsides the loess mantle seems to be thicker, and under tussock grassland the upper part of the A horizon is characterised by strong granular structure. A typical profile of the Sherwood silt loam - hill phase is:

A_1	11"	very dark greyish brown; very friable silt loam with strong granular structure giving way to moderate nutty structure in a narrow transition to the B horizon,
B_2	10"	light yellowish brown; friable silt loam with moderate nutty structure; many fine yellowish brown mottles possible due to clay spotting,
B_{3g}	4"	very pale brown; friable silt loam with weak platey structure; many orange mottles; thin clayskins along veins which penetrate into,
C/D	on	yellowish brown; moderately compact, massive, heavy silt loam; few light grey mottles; brown clayskins in pores and lining channels.

A thin 3-4 inch transitional horizon characterised by aestivation burrows is usually present between the A and B horizons. B horizon colours may vary from light yellowish brown to pale olive and occasionally fine black manganese speckles may be seen towards the base of the B horizon. A stony phase of the Sherwood Hill soils has been identified and is characterised by occasional subangular and angular greywacke stones occurring in the B horizon. Probably due to the downhill creep of greywacke slope detritus during the accumulation of the loess which forms the parent material of this soil.

- Chemistry and Mineralogy

Analysis of a profile from the Mowbray area indicates that levels of exchangeable bases and the cation exchange capacity are lower than modal values, but C/N ratios, nitrogen levels and base saturations compare favourably with the type profile (Kear et al 1967). The crystalline clay fraction is dominated by illite and interlayered hydrous micas with subsidiary, equivalent amounts of clay-vermiculite (1), clay-vermiculite (2) and chlorite.

(b) Opuha Series

i. Described elsewhere - environmental range

Although commonly derived from thick accumulations of loess, the soils of the Opuha series, particularly on strongly sloping hillsides, have been recorded as developing over deposits of mixed loess and colluvial materials (Raeside and Baumgart 1947, Raeside et al 1959, Kear et al 1967). They occur over rolling to moderately steep lands under a climate which is characterised by 23-25" of rainfall (although Raeside suggests 30-40") and do not experience the extremes of temperature and marked seasonal droughtiness that influences the Sherwood soils.

- Modal Profile

They are characterised by somewhat impeded drainage which gives rise to a pale yellowish brown or brownish grey silt loam B horizon with many orange and rusty mottles. This horison displays only weak nutty structure and gives way below about 18" to a yellowish brown, compact, massive C horizon. This soil is less acid and less unsaturated than the Sherwood soils but levels of most cations and base saturation are considered low (Metson 1961).

ii. This survey - environment

The occurrence of Opuha soils in the Mowbray area is restricted to a series of small sheltered locations, on low, often concave hillsides of northerly or northwesterly aspect. They occur up to about 2,700 ft above sea level and probably receive less than 35" of precipitation annually. They support a mixed sward of dominantly hard tussock and brown top with scattered matagouri and broad-leafed snow tussock.

- Morphology

Opuha soils display A_1 / AB / B_2 / BC or B_3 / C or D horizonation. They have 6 to 8" of A horizon with moderately developed granular structure over a thin transitional horizon to a B horizon, which extends to a depth of between 17 and 20 inches. The B horizon varies between yellowish brown and light brownish grey in colour, is usually mottled with yellow and orange colours and displays weak nutty structure. There is usually a transitional BC or B_3 horizon above the C (or D) which is strongly mottled and compact, and either massive and structureless or displays weak prismatic structure. One type, the Opuha silt loam and a hill phase have been mapped. A typical profile of the Opuha silt loam is:

A_1	6"	dark greyish brown; friable silt loam with moderately developed granular structure,
AB	4"	greyish brown, transitional horizon; friable silt loam with moderate to weakly developed nutty structure,
B_2	13"	pale yellowish brown; firm silt loam with weak nutty structure; many yellowish brown mottles,
BC	3"	pale olive, transitional horizon; weakly structured firm silt loam,
CD	on	yellowish brown; slightly compact and massive silt loam; many light grey and orange mottles.

Morphologically, there appears to be little difference, in the Mowbray area, between these Opuha soils on rolling terrain and those on strongly sloping hillsides except that on rolling terrain, A horizons do tend to be thicker, and there is generally a greater thickness of solum. Occasionally on strongly sloping hillsides, the compact C (or D) horizon is absent and the stony lower solum overlies an uncompacted layer of mixed loess and colluvium below 14" to 16" depth. Laterally the solum thickens to give the normal Opuha hill soil (silt loam). This shallow phase has not been mapped separately but is indicative of both the variability likely to be encountered amongst soils of this series, and the relatively shallow depth of loess accumulation on such hillsides.

- Chemistry and Mineralogy

The analysis of a representative Opuha soil from the Mowbray area is very similar to the modal analytical data for this series. Exchange capacity, however, is nearer the lower limit and as exchangeable cation levels are similar to the modal, the calculated base saturation is medium rather than low. As with the Sherwood series the Opuha series appears to have the crystalline clay fraction dominated by illite and interlayered hydrous micas with subordinate but equivalent amounts of chlorite, clay-vermiculite (1) and clay-vermiculite (2).

(c) Clayton Series

i. This survey - environment

A new series established tentatively during this survey, the Clayton series, occurs over a wide range of terrain classes from near level to strongly sloping. Soils of this series occur in concave footslope locations adjacent to both low and high hills, at sites of distinct breaks in slope where the flushes occur. They also occur along broad shallow drainage channels in loess covered fans, particularly the upper fan of the Meikleburn. Clayton soils are poorly drained because they are receiving sites from both seepage waters and surface runoff. Consequently they vary considerably in morphology, depending on the degree, intensity and permanence of saturation, the nature of the surface, and the angle of slope. In areas of recent loess accumulation they are developed over loess or rewashed loess. On strongly sloping surfaces they are usually derived from rewashed silts from eroding hillsides but often contain gravels and stones, both within the profile, and at shallow depth. In these locations they almost invariably reflect some characteristics of the several adjacent soils. They usually support a dense cover of red tussock and associated hard tussock. Tall rushes are common on the less steep slopes (Figure 16).

- Morphology

Clayton soils on gently sloping footslopes below loess covered hillsides have moderately thick sola with distinct gleyed horizons. They have 10" of A horizon over a transitional horizon to a heavy textured gley horizon which rests on a gritty slightly compacted gleyed C horizon, i.e. an A_1 / ABg / BG / CG or Cg horizonation. A typical profile of the Clayton silt loam is:

A_1	10"	greyish brown; plastic and sticky silt loam with moderate granular and very fine nutty structure; common brown stains along root channels,
ABg	6"	transitional; variegated orange and light olive grey; friable, heavy silt loam.

(II) BG	5"	light grey; firm silty clay loam with moderate blocky structure; many orange mottles; few black manganese specks,
(III) Cg	on	variegated, light grey and orange; moderately compact and massive, gritty silty clay loam.

(Water level at 16")

Sorting of sediments washed from the adjacent hillsides subsequent to the deposition of loess is responsible for the layering in these soils and the heavy textures of the B horizons. In many locations the upper part of the A horizon is commonly a muck (Leamy and Panton 1966) or is turfy (Soil Bureau Staff 1962 p. 115).

On the other hand on gently sloping fan surfaces in areas of poor drainage, Clayton soils generally have slightly coarser textured profiles and less pronounced gleying. The coarser textures result from the current weathering of the underlying older loess in the slightly eroded broad channel sites occupied by these soils. A typical profile from the upper Meikleburn fan is:

A_1	12"	dark grey; highly humic, silt loam,
Bg	7"	light olive grey; silt loam; many distinct orange mottles,
Cg(x)	on	variegated, grey and orange; slightly compact, gritty silt loam.

(Water level at 8")

In the region of seepages at the footslope of moderately steep hillsides and commonly at concave breaks in slope in such terrain the Clayton hill soils occur. In such locations they are subject to both surface and subsoil flushing. Water is usually at or near the surface, and a relatively deep, humic surface horizon is often present. Gley features are not so pronounced and stones commonly occur between 12" and 18". A typical profile of a <u>Clayton silt loam - hill phase</u> is:

A_1	10"	dark grey; gritty silt loam; with turfy upper surface,
(II) Bg	10"	pale olive; gritty heavy silt loam; common orange mottles; some manganese specks,
	on	light grey; gritty silt loam; manganese specks; many pale olive and orange mottles.
		(occasional small stones throughout profile)

Stony and very stony phases with stones below 12" and 6" respectively have been recognised but have not been mapped separately.

Initially, this series was correlated with the Waitohi soils of adjacent regions (Raeside et al 1959, Kear et al 1967), Soil Bureau Staff 1968a). The drainage characteristics and the landform associations, however, are quite different despite the occurrence of both soils in proximity to Skipton and Opuha series. In fact, it may be said, that previous surveys have done little to identify and separate gleyed soils caused by flushing (e.g. Clayton series). Rather, such soils have been grouped as phases or sub-types of adjacent soils. A new series was separated on this survey because it was considered to be an integral, yet distinctive part of the soil landscape. On a broader scale, however, due to the small areal occurrence, Clayton series would almost certainly be incorporated, or associated, with adjacent soils in much the same way as it has been necessary to associated small areas of this kind of soil with the Sherwood and Skipton series, on this survey.

(d) <u>Skipton Series</u>

i. Described elsewhere - environmental range

Soils of the Skipton series were considered by Raeside et al (1959) and Kear et al (1967) to be soils of the downs margins (generally occurring on terraces of low relative relief, with imperfect drainage and receiving between 30" and 40" of rain annually. They are developed over loess and resorted loess and are normally associated with the Opuha, Sherwood and Kakahu soils.

- Modal profile and chemistry

A dark greyish brown silt loam overlies a pale yellowish brown to pale greyish yellow, strongly mottled silt loam B horizon which in turn rests on a firm, massive, strongly mottled pale yellow or yellow silt loam C horizon. Skipton series is strongly acid and has low levels of exchangeable cations and a low exchange capacity. It usually has a slightly better nutrient status than the Sherwood series but base saturation figures and exchangeable cation levels are lower than those of the Opuha series.

ii. This survey - environment

In the Mowbray catchment two site conditions occur. Firstly, the Skipton series occurs on older, moderately sloping fans and on low hill surfaces. Secondly, hill soils related to the Skipton series occur on the less steep upper parts of low, convex hillsides above the Opuha and Sherwood series (Plate 9). They receive a greater amount of precipitation and are subject to a wider range of temperatures than the Skipton series proper. It has consequently been necessary, during this survey, to extend the concept (outlined above) of the Skipton soils. Skipton series are derived from loess and resorted loess on gently to strongly sloping terrain up to 2,500 ft above sea level, and receive between 30" and 35" annual precipitation. Drainage is impeded by the presence of a compact "loess-pan" in the lower solum or sub-solum.

- Morphology

A 2" to 3" transitional horizon separates a very dark greyish brown, silt loam A horizon with strong granular and very fine nutty structure from a light yellowish brown to pale olive, silt loam B horizon below 10". The B horizon has moderately developed nutty structure and gives way to a compact, massive light yellowish brown, heavy silt loam or sandy clay loam, older loess in the position of a D horizon below 20". Pale olive and orange mottles are common in the lower solum. Skipton series commonly shows an A_1 / AB / B_2 / B_3 or BC / C or D horizonation.

The Skipton silt loam is developed over loess and possibly resorted loess. Drainage varies from imperfect to poor and in poorly drained sites this soil merges to the Clayton silt loam. Vegetation comprises a close sward of browntop, sweet vernal and hard tussock, with scattered matagouri and broad-leafed snow tussock. A typical profile is:

A_1	6"	very dark greyish brown; silt loam,
AB	4"	dark greyish brown; silt loam; common rusty mottles along root channels,
B_2	11"	light yellowish brown; silt loam; many orange and light brownish grey mottles,
D	on	pale yellow; moderately compact silt loam; many pale olive and yellowish brown mottles.

Structure is strongly to moderately developed throughout the upper solum and ranges from granular in the A to nutty in the B. The mottling and moderately developed structures in the B horizon help to characterise this soil. In addition, iron concretions and manganese speckles are commonly found in the lower

B horizon. Raeside et al (1959) identified a "Skipton silt loam with concretions", but this phase has not been separated here as it is considered that the occurrence of either concretions or distinct orange mottles is a normal feature of the Skipton silt loam in the Mowbray area.

On hillsides, the Skipton hill soils are generally closely associated with the Sherwood hill soils but occur in upslope locations where rainfall is higher. In these sites profiles are less mottled than the type and usually give way to a weakly compacted C horizon between 16" and 18". Below 24" colluvial gravels may occur. Manganese specks and iron concretions are not as common and are only found in moister, imperfectly drained sites. A mixed sward of broad-leafed snow tussock, hard tussock and rare silver tussock, with introduced grasses covers these soils. A typical profile of the Skipton silt loam - hill phase is:

A_1	6"	dark grey; very friable silt loam with moderate to strong granular and very fine nutty structure,
AB	5"	greyish brown; friable silt loam transition to the B horizon,
B_2	5"	light yellowish brown to pale olive; firm silt loam with moderate fine nutty structure; common pale olive and brownish yellow mottles,
CD	on	light yellowish brown; very firm silt loam with very weak coarse nutty structures; many light grey and yellowish brown mottles; few thin brown clayskins in some pores and lining channels.

- Chemistry and Mineralogy

There is very little chemical data available on the Skipton soils and the one Skipton analysis from the Mowbray area compares favourably with the published data. Base saturation figures

Plate 8 - Looking up the Mowbray gorge. Tasman soils on the lowest terraces, passing through Ashwick soils on intermediate terraces, Mowbray soils on the highest terrace remnants and Kakahu hill soils on the hillside.

Plate 9 - Slight irregular hollows seems to be a feature of the surface of the Skipton hill soils. They may be a result of minor slumping with movement occurring along the upper surface of an underlying older loess layer.

seem to be slightly higher in the Mowbray area but are still low by overall standards (Metson 1961), and both organic carbon and nitrogen levels are lower than analytical figures given by Kear et al (1967). Interlayered hydrous micas, illite, clay-vermiculite (2) and metahalloysite dominate the crystalline clay fraction. Chlorite and clay-vermiculite (1) are present in only minor amounts.

(d) Kakahu Soils

i. Described elsewhere - environmental range

Kakahu soils occur extensively over the downs and downs margins of Canterbury and North Otago. They occur over rounded spurs and on undulating to hilly terrain. One type, the Kakahu silt loam, has been separated and the shallower related hill soil phase of this type occurs on strongly sloping hillsides. These moderately well drained soils are derived from loess which is generally at least 24" thick but on the steeper surfaces the loess may be thinner, overlying mixed loess and colluvial greywacke debris. Kakahu soils have been recognised under a rainfall range of 28" to 45" and up to an elevation of 2000 ft above sea level.

\- Modal Profile

A typical profile usually displays a thin, very dark greyish brown silt loam A horizon with only weakly developed nutty and granular structure over a very thin transitional horizon to a light yellowish brown, friable to firm, weakly structured, silt loam B horizon. The C horizon is of similar colour and texture and is distinguished by its very firm consistence and marked increase in the numbers of yellowish brown mottles. Kakahu series is generally moderately acid with a medium exchange capacity and low base saturation and low levels of exchangeable cations.

ii. This survey - environment

Within the Mowbray area two types occur, the Kakahu silt loam and the Kakahu stony silt loam and each has a related hill phase. These soils are developed from a thin layer of loess over a slightly compacted layer of mixed loess and greywacke colluvial debris. In general, the steeper the slope the thinner the surface loess layer. It seems that erosion, following the initial deposition of the upper loess, reduced the thickness of stone free material in the upper profile and that, in places, later (or contemporaneous) mixing due to creep and/or solifluction has brought stones into the upper part of the profile giving rise to the Kakahu stony silt loams.

The soils of the Kakahu series occur adjacent to and at higher elevation than the Skipton, Sherwood and Opuha soils. They are found on the upper parts of the rolling and hilly hill-sides of the watershed upland under a hard tussock-exotic grass association which includes scattered broad-leafed snow tussock and rare matagouri. On hilly phases, the proportion of Chionochloa sp. increase and Celmisia sp. becomes prevalent on southern aspects. Kakahu soils experience a precipitation of 30-35" annually and are found up to 3000 ft above sea level.

- Morphology

The Kakahu silt loam on undulating and rolling terrain is essentially similar to the broad description given above. A typical profile is:

A_1	6"	very dark greyish brown; very friable silt loam with moderate granular structure,
B_1	3"	yellowish brown to light olive brown; friable silt loam transitional horizon with strong cast granular structure,

B_2	5"	light yellowish brown; friable silt loam with moderate nutty structure,
BC	on	pale yellow; firm or very firm silt loam with weak to moderate nutty structure; few orange mottles; occasional subangular greywacke gravels and stones. Textures become sandier with depth and stones become more prominent below 24".

- the structures are slightly better developed throughout than in the modal concept, and mottles in the lower solum are fewer. The latter feature may be a result of the lower precipitation experienced by these soils in this area and the former may be attributed to a more intensive soil faunal activity. These soils exhibit an A_1 / B_1 / B_2 / BC / C or D horizonation.

The related hill soil of this type shows essentially the same features as the profile above except for a distinctly gritty feel in the texture of the B horizon, the common occurrence of angular greywacke gravels and stones in the B horizon and commonly, a stony fine sandy clay loam texture in the C horizon. Profile MC 81 (Appendix 1) illustrates this phase (see also Plate 10).

The Kakahu stony silt loam has a similar appearance, except of course for the occurrence of stones throughout the profile. Stones occur in the A horizon and usually within 6" of the surface. Matagouri is more common than over the Kakahu silt loam. It is not uncommon in many places to find a stony A horizon over a B horizon, which is relatively stone free, resting on a stony, or very stony C horizon. Stones are generally not apparent on the surface of this soil. The hilly phase on the other hand has stones throughout the solum, which rarely exceeds 16" in thickness, and stones are scattered over the surface. Soils of this type tend to show an A_1 / AB / B_2 / (BC) / C or D horizonation.

A typical <u>Kakahu hill soil (stony silt loam)</u> is:

A_1	7"	very dark greyish brown; very friable; slightly stony silt loam with weakly developed granular and crumb structure,
AB	3"	dark greyish brown; very friable, stony silt loam with moderately developed nutty structure,
B_2	6"	light yellowish brown; friable, very stony silt loam with moderately developed nutty structure,
C	on	light yellowish brown; friable very stony, fine sandy clay loam.

An eroded phase of the Kakahu stony silt loam has been identified but has not been mapped separately. This soil has a very thin (2"-3") A horizon on 6"-8" of light yellowish brown stony silt loam, B horizon over a very firm pale yellow BC horizon. Stones occur throughout the profile. This phase is confined to small steep areas in the heads and sides of small eroding gullies.

- <u>Chemistry and Mineralogy</u>

Apart from the exchange capacity which is lower in all horizons, the Kakahu silt loam follows closely the modal concept of this type. Exchangeable cations and base saturation are low and carbon/nitrogen ratios are medium to high. The related hill soils which are very strongly leached have very low base saturations, very low levels of exchangeable cations except potash, which unpredictably, is of medium levels (Metson 1961), and high carbon/nitrogen ratios. The higher altitude location of these soils relative to the Kakahu silt loam, and their receipt of slightly higher precipitation and runoff from above, coupled with their acquisition of previously weathered materials by slope

Plate 10 - Kakahu silt loam - hill phase, Notice the contrast between the A horizon of this profile and that of the profile in Plate 11.

Plate 11 - Tengawai hill soil (stony silt loam). Notice the irregularly sorted mixed loess and colluvial material of the compact subsoil. A thin accumulation of recent loess overlies this mixed deposit.

wash, could adequately explain the obviously stronger leaching in these soils.

Kakahu series is dominated by chlorite, illite and interlayered hydrous micas in the crystalline clay fraction. But, more specifically the hill phases are dominated by chlorite, interlayered hydrous micas and clay-vermiculite (1), while those on rolling terrain have higher percentages of illite instead of clay-vermiculite (1). The Kakahu silt loam also contains anomalously, moderate amounts of metahalloysite.

(4) Soils of the Hilly and Steep Hillsides

A wide range of soil types and environments are encompassed by this physiographic grouping.

Soils vary from weakly weathered, moderately to strongly leached yellow-grey earths, to moderately weathered, very strongly leached high country yellow-brown earths and intergrades to skeletal soils. Rainfall varies from 30" to 40" annually and altitudes range from 2,000 ft to more than 5,000 ft above sea level. At the lower elevations vegetation is dominantly short tussock grassland (fescue - tussock grassland of Connor 1964). In most locations this grassland appears to conform with "Association B" of Barker (1953 p. 28) which has subdominant matagouri. Above 3,000 ft (Connor says 2,800 ft for the Mackenzie) the short tussock grassland gives way to a snow tussock grassland on exposed aspects facing NE to NW. This association is found at lower altitudes (2,200 ft) on SE to SW aspects, where Celmisia spectabilis becomes subdominant (Plate 5). On higher slopes of northerly aspect where burning has recently occurred Celmisia spectabilis appears dominant (see Plates 13, 15).

At lower altitudes most soils are developed on mixed loess and greywacke colluvial detritus. At higher altitudes and on steeper slopes, where the contributions of aeolion material have been considerably less, and removal by sheet erosion has been more effective, the soils are developed from greywacke colluvial materials and also directly from weathering greywacke rock, in places on ridge crests.

The occurrence of loess under colluvium in the Puketeraki and Lookout soils, and a small area of Tengawai hill soils, on the eastern margin of the upper basin is indicative of a previous period of stability when loess accumulation and rock weathering took place in situ. The activity of drift regime has effectively removed any such loess accumulations from more exposed sites, where Tekoa and Kaikoura series occur, and has led to mixing of loess and colluvial debris in the parent materials of the Puketeraki and Lookout series. The acquisition of recent deposits of loess, derived from adjacent eroding hillsides, on the more sheltered aspects of the upper basin occupied by the Puketeraki, Lookout and Tengawai series, is a possibility which should not be overlooked.

Tengawai series occurs in exposed hillsides and adjacent to ridge crests at higher elevations than the Kakahu series. Soils of the Tengawai series are derived from mixed loess and colluvium and often have a surficial very thin loess deposit (Plate 11). They generally exhibit stony profiles of moderate depth which have rapid through drainage. They display pale coloured subsoils, firm and very firm consistence, and weak weathering, as indicated by a predominance of illite and interlayered hydrous micas. All features which are indicative of soil formation in the yellow-grey earth zone (Pohlen 1967, Fieldes 1962).

Above 3000 ft (approximately) or on moist well shaded aspects the Tengawai soils give way to soils of "yellow-brown" basal form (Soil Bureau Staff 1968b Part 1 p. 21, and Pohlen 1967). In the Mowbray region the predominant subsoil colour of such soils is brown or pale olive brown. These soils are almost invariably stony and are thin or of moderate thickness. They have been extensively eroded in recent times (Gibbs et al 1945). These soils are friable throughout the solum and have distinct crumb-like aggregation in their topsoils and crumb and fine nutty structure in the subsoils.

Lookout and Puketeraki series are derived from mixed deposits on old talus, high angle fans and steeply sloping hillsides. They are generally well vegetated and in many locations Celmisia sp. dominates. They are almost invariably found on south or southwest aspects and show a thicker profile with greater development than other "yellow-brown" soils of this group. Lookout series occurs at lower altitudes than 3000 ft and gives way up hill to the more distinctly yellowish-brown, Puketeraki series. Buried horizons of former soils are a common feature of both soils (see Figs 24, 25).

Tekoa and Kaikoura series are found on stony eroding hillsides of northeasterly or northwesterly aspect. Tekoa series occurs at lower elevations than the Kaikoura soils, on the steeply sloping parts of hillsides above concave lower slope locations. Kaikoura soils occur at higher elevations than the thinner Tekoa soils (which have relatively shallow colluvial veneers over bedrock) and include hill soils on ridge crests. Deep colluvial deposits on these hillsides probably derive in part from eroding old once stable surfaces parts of which are represented by the buried horizons in the Lookout and Puketeraki soils. On ridge crests the soils are thin and overlie weathering greywacke in places.

Lookout series has granular and crumb structured, stony A horizons which are thicker than the stony, generally crumb structured A horizons of the Puketeraki series. (B) horizons of both series tend to be light olive brown or light yellowish brown, are stony and have nutty and crumb structures. The generally shallower Tekoa and Kaikoura series have stony or very stony crumb structured A horizons. In the subsoil, the BC horizons are brown or yellowish brown, very stony and have weak crumb structures. Tekoa series is separated from Kaikoura and Puketeraki soils by weaker profile development and a thinner solum.

Kirkliston hill soils are found in only one small location which is thought to be part of an old moderately, deeply weathered, once far more extensive, peneplain surface (Gair 1962). These are the only "yellow-brown" soils which have a moderately deep stone free solum with a brownish yellow B horizon.

Tengawai soils have been classified as hill and related steepland yellow-grey earths. Lookout and Puketeraki soils and Kirkliston hill soils are considered to be upland and high country yellow-brown earths. The Kaikoura and Tekoa soils are upland and high country yellow-brown earths in part and in places intergrade to skeletal soils.

(a) Tengawai series

i. Described elsewhere - environmental range

Kear et al (1967) in describing the Tengawai series noted only one mapping unit, the "Tengawai stony loam" and considered that it occurred only on steeplands. Soil Bureau Staff (1968a), grouped the Tengawai soils as:

"24a Tengawai steepland soils" - including "stony silt loams and silt loams, mostly shallow".

"24aH Tengawai hill soils" - including "silt loams and stony silt loams".

Both groups of authors agree that these soils occur over greywacke colluvium, greywacke rock (particularly in upper slope locations) and greywacke gravels with a thin cover of loess. These soils occur on steep and moderately steep hillsides, often with rock outcrops, up to an altitude of 3500 ft above sea level and in a zone receiving between 20" and 30" of rain.

- Modal Profile

The type profile (Soil Bureau Staff 1968a p. 35) has:

A	8"	very dark brown; firm stony silt loam with strong granular structure, indistinct boundary,
B	12"	pale yellowish brown; firm stony silt loam with strong nutty structure; indistinct boundary,
C	on	pale yellow; firm, very stony, heavy silt loam; massive with fine blocky structure; few distinct yellowish stains.

The Tengawai soils are only moderately acid with medium exchange capacities and base saturations, and generally medium levels of exchangeable bases.

ii. This survey - environment

Within the Mowbray catchment Tengawai series is found on both hilly and steep lands. Tengawai steepland soils are almost invariably very stony silt loams. Tengawai hill soils which occur as silt loams and stony silt loams are found on strongly sloping and strongly to steeply sloping hillsides, often extending into down-slope concave accumulative locations adjacent to Kakahu hill soils, and on convex, regressive, moderately steep ridge crests. Tengawai series on hills are formed over mixed loess and greywacke colluvial materials on colluvial debris or shattered greywacke bedrock. In some locations, especially adjacent to broad ridges where a thin veneer of loess has accumulated, or near breaks in slope on some of the higher ridges on sites where finer slope wash materials have tended to accumulate, the soils tend to be the Tengawai silt loams. Elsewhere they are stony silt loams.

- Morphology

Tengawai silt loam generally has a continuous cover of broad-leafed snow tussock, hard tussock and exotic grasses, with scattered matagouri. In slightly moister locations, particularly towards the head of valleys, matagouri gives way to blue tussock and scattered Celmisia sp. A representative profile is:

A	9"	very dark-greyish brown; very friable, gritty silt loam with strong granular structure tending to nutty with depth,
B	3"	yellowish brown; very friable, gritty silt loam with strong nutty structure,
BC	5"	light yellowish brown; friable, stony silt loam with moderate nutty structure; common angular greywacke gravels and stones,
C	on	light yellowish brown; friable, stony silt loam with weak nutty structure; common angular greywacke gravels and stones, becoming extremely stony below 26". Stones are moderately weathered.

Tengawai stony silt loam is fairly uniformly covered by a broad-leafed snow tussock - hard tussock association with subdominant matagouri. A profile of this soil type is:

A	7"	very dark greyish brown; very friable, stony silt loam with moderately to strongly developed granular structure tending to nutty with depth; common subangular weakly weathered gravels,

AB	3"	brown; friable, stony silt loam with moderate nutty structure; common subangular gravels and stones,
B	3"	olive brown; friable, stony silt loam with moderate nutty structure; common stones and gravels,
C	on	light yellowish brown; friable, stony silt loam with weak nutty structure becoming firmer and stonier with depth; extremely stony below 22".

Tengawai very stony silt loam formed on steep slopes is generally of gritty texture, has rapid through drainage, thin sola, and is generally found on "shedding sites". All of these factors are consistent with the occurrence of these soils (and related stony hill soils) in an area of higher precipitation than normally accepted for this set (Soil Bureau Staff 1968a). The vegetative cover is incomplete and more bare ground is seen than is the case with other members of this series. Broad-leafed snow tussock, hard tussock and matagouri incompletely cover a surface of scattered stones, bare soil and small rock outcrops. A typical profile over colluvial material is:

A	3"	very dark greyish brown; very friable, stony, gritty silt loam; angular gravels and stones,
AB	5"	dark greyish brown; very friable, very stony, gritty silt loam; angular gravels and stones,
BC	3"	olive brown; friable, very stony, gritty silt loam to sandy loam; stones becoming increasingly abundant below 14".

The profile is even thinner near rock outcrops where matagouri and hard tussock become the dominant vegetation. A profile from such a site is:

A	5"	dark brown; very friable, stony silt loam with weak granular and crumb structure; a range of coarse fragments from subangular gravels to angular large stones,
AC	on	brown; very friable, extremely stony, silt loam with weak crumb structure; gravels and stones increasing rapidly with depth to large boulders of shattered greywacke.

On steep slopes Tengawai very stony silt loam, in some respects, has the appearance of an eroded phase of the Tengawai silt loam or the Tengawai stony silt loam. However, as the very stony silt loam has an almost equally well developed solum, even on steeper slopes, where one might expect the opposite to be the case, it is considered to be a distinct and separate soil type, and not an eroded phase of a related type. This makes the separation and identification of eroded phases of the Tengawai series difficult. As a consequence, for mapping purposes, when eroded phases of the Tengawai silt loam or Tengawai stony silt loam are found on steeper slopes, they have been grouped with the Tengawai very stony silt loam. On less steep sites, eroded phases have been grouped with the appropriate type.

- Chemistry and Mineralogy

One Tengawai silt loam profile and two Tengawai stony silt loams were analysed. All results conform with those from other Tengawai soils (Soil Bureau Records), but are generally towards the lower limits of the ranges for base saturation and exchangeable cations. Carbon/nitrogen ratios are generally higher than values here considered medial, and exchange capacity is also below the medial concept in all horizons. The mineralogy of the crystalline clay fraction compares with that considered typical of weakly weathered yellow-grey earths (Soil Bureau Staff 1969b). Illite and interlayered hydrous micas are the dominant clay minerals. Clay-vermiculite (1) dominates over clay-vermiculite (2) which is also subordinate to minor amounts of chlorite present.

The three profiles examined chemically and mineralogically are developed from:

44 - loess on mixed loess and colluvium over greywacke rock;

72 - very thin loess on mixed loess and colluvium on colluvium;

85 - mixed loess and colluvium on mixed loess and colluvium.

Because of the overall similarity of their chemistry and mineralogy it is considered that the material, of a varied physical, chemical and mineralogical nature, which underlies the solum has little influence in the development of the current profiles.

(b) Lookout Series

i. Background - The Lookout series, which is described here for the first time is very closely related to the Puketeraki set. Soils of the Puketeraki set have been described (Soil Bureau Staff 1968a, 1968b) as occurring between 3000 and 5000 ft above sea level on "rolling to easy rolling and some moderately steep and steep" (Soil Bureau Staff 1968a p. 268) terrain under a rainfall of between 40" and 80" annually. In other places in this thesis, soils conforming with the modal of a given set, but occurring outside the considered environmental range of that set, have been given the set name and the limits of that set have been widened. The Puketeraki soils, however, have been defined in terms of a reference profile (Soil Bureau Staff 1968b) and consequently those similar soils falling outside the requisite environmental range, as in the case of the Lookout series, have been given a separate and new name.

ii. This survey - environment - Lookout series is found on strongly to steeply sloping and steeply sloping hillsides between 2500 and 3000 ft above sea level, on southerly or westerly aspects. Precipitation averages 35 to 40 inches annually, and due to the shaded aspect is probably more effective than the figures indicate. Soils of this series occur at lower elevations than Puketeraki and Kaikoura soils, but adjacent to Tekoa series and on shaded aspects of the lower altitudinal limit sometimes associated with Tengawai soils. They are found on well drained sites, but are subject to accumulation of eroded material from above. They are derived from an intimate mixture of loess and colluvial materials and may overlie buried horizons of older truncated soils (MC 64, Appendix 1) or colluvial material.

- Morphology

The A horizon is a dark greyish brown or dark brown, very friable, stony, gritty silt loam with weakly to moderately developed granular and crumb structure. Stones of angular greywacke detritus are moderately weathered. A stony, gritty silt loam transitional horizon of variable colour; usually brown to light yellowish brown, overlies a brown to light yellowish brown, friable, stony gritty silt loam with moderately developed granular and nutty structure. This B horizon is in turn underlain by a light yellowish brown friable, stony or very stony, gritty silt loam with weakly to moderately developed nutty and weak crumb structure. A typical profile of the Lookout stony silt loam is:

A_1	9"	dark greyish brown; very friable, slightly stony silt loam with weak to moderate granular and crumb structure; few, angular, moderately weathered greywacke stones,
AB	4"	brown; friable, stony, gritty silt loam with moderately developed granular and weakly developed nutty structure; common angular greywacke stones,

B	5"	yellowish brown; friable, stony, gritty silt loam with moderate to weak nutty structure; common angular greywacke stones,
C	on	light yellowish brown firm, very stony silt loam with weak to moderate nutty and crumb structure and many angular greywacke stones and boulders.

The surface of this soil is generally free of stones. Typically this series shows A_1 / AB / B or (B) / BC horizonation.

- Chemistry and Mineralogy

Analyses indicate a very strongly leached soil which is strongly acid and has low exchange capacity and nitrogen levels, and very low levels of exchangeable bases. Mineralogical investigation of the crystalline clay fraction reveals that illite and interlayered hydrous micas are dominant with equivalent levels of chlorite and clay-vermiculite (2) and only subordinate amounts of clay-vermiculite (1) and metahalloysite.

Only one type, the Lookout steepland soil (stony silt loam) has been mapped. An eroded phase of this type, characterised by a semi-continuous surface covering of large stones and a relatively thin A horizon was identified but is not shown on the "Soil Map", but does appear on Traverse 5 on the plot of the "Detailed Traverses".

Lookout series is differentiated from the Puketeraki and Kaikoura soils by a thicker solum (Fig. 24), generally paler subsoils, their occurrence at elevations below 3000 ft above sea level and the generally stone free nature of their surface. They are separated from the Tengawai soils by their occurrence in moister sheltered aspects, the more weathered nature of greywacke fragments in the subsoil and the presence of distinct crumb structures throughout the profile.

Because of the tendency towards the development of 10YR hue colours in the B horizon, the presence of crumb structures throughout the solum and the lack of a compact horizon these soils have been grouped with Puketeraki soils as hygrous, upland and high country yellow-brown earths (eldefulvic soils).

(c) Puketeraki Series

i. Described elsewhere - environmental range

Soils of the Puketeraki set occur on moderately sloping and strongly sloping upper fan and stable scree surfaces adjacent to the high mountains. They are derived from colluvial and solifluction greywacke detritus with an admixture of loess blown off adjacent slopes, and sometimes with a thin capping of loess and/or fine slope-wash. They support a cover of snow tussock and Celmisia sp. often separated by bare ground; experience a rainfall of between 40" and 80" and occur between 3000 and 5500 ft above sea level. These soils are considered to have developed under beech forest. However, an average upper tree-line at 4,500 ft or even 5000 ft during the climatic optimum, if one is to accept the postulated higher upper limit of Wardle (1963), still leaves the development of these soils taking place, in part, in a zone of alpine grassland and/or shrubland.

- Modal Profile

Profiles described from areas which are no longer forested reveal a dark greyish brown, very friable, crumb structured silt loam A horizon over a yellowish brown, silt loam to loam B horizon which has friable consistence and weakly developed crumb and nutty structure. The underlying C horizon tends to be a firm, pale yellowish brown, stony silt loam or loam with weak nutty structure. Puketeraki soils are moderately acid and very strongly leached. Cation exchange capacity varies from medium to low and exchangeable bases are low except for potassium which has medium levels.

Data given for the type profile of the Puketeraki silt loam (Soil Bureau Staff 1968b) seems to indicate a composite origin for that soil. Drift of more recent material, either from upslope or by wind borne accretion has accumulated on an older more stable surface. Composite soils, described by Molloy (1964) and the author in Hayward (1969) appear to be a feature of the Porters Pass area, the location of the Puketeraki reference site (Soil Bureau Staff 1968b). Thus it is not unreasonable to assume a polygenetic origin for the Puketeraki silt loam at that site.

Due to the almost level terrain and the composite profile this soil is not typical of the Puketeraki set (Cutler, pers comm). However, Gibbs (pers comm) has said that as it has now been established as a "reference site" it must be considered as modal for these soils. Consequently, when morphologically similar soils were encountered on steep slopes in the Mowbray catchment it was decided to map them as steepland soils related to the Puketeraki set.

ii. <u>This survey - environment</u> - Within the Mowbray area, Puketeraki series is for the most part, confined to steeply sloping hillsides of southern or westerly aspect. As noted, soils have been mapped as a steepland phase of this series. A Puketeraki silt loam and a Puketeraki stony silt loam have been recognised. A small area, too small to map, of a Puketeraki hill soil (silt loam) was recognised high on the watershed (see MC 84 Appendix 1) and this profile conforms very closely with the modal concept of the type. Rainfall is in the region of 40-45" annually and the sheltered aspects enhance the effectiveness of the incident precipitation.

Soils of the Puketeraki series in the Mowbray catchment are found under an often discontinuous cover of snow tussock (broad-leafed snow tussock at lower elevations and narrow-leafed snow tussock at higher levels), Celmisia sp., blue tussock and hard tussock, often with much bare ground. Distinct "loamy" screes occur in association with this soil and are considered as an eroded phase of it.

- Morphology

These soils have a dark greyish brown or dark brown, gritty silt loam A horizon which has moderately developed crumb and granular structure. A brown, gritty silt loam transitional horizon gives way to an olive brown B or (B) horizon below 10" to 12". The B or (B) horizon has a gritty silt loam texture and is commonly stony, although it generally is less stony than the horizons above. The greater stoniness of the upper horizons may be due either to more recent accumulation of drift material on an older soil or result from the erosion of the fine component leading to a resultant concentration of the coarse earth fraction. Moderate nutty and crumb structures in the B or (B) horizon give way to weak crumb structure in the olive brown, extremely stony BC/C horizon which occurs below 15". The Kaikoura soils in the Mowbray area, by contrast have stonier, and more uniformly stony profiles, yellow brown colours in the BC horizon, a thinner solum and show A / AB / BC / C or D horizonation.

The Puketeraki silt loam on steeplands has a more mixed vegetation association than the stony silt loam. A representative profile of the former is:

A	6"	dark brown; very friable, gritty silt loam with moderate crumb structure,

AB	5"	brown; very friable, stony, gritty silt loam with weak to moderate crumb structure and fine nutty structure; common, weakly weathered, angular, greywacke gravels and large stones,
(B)	4"	olive brown; friable, very stony, heavy silt loam with weak to moderate crumb and fine nutty structure; many, weakly weathered, angular greywacke gravels and large stones,
C	on	light yellowish brown; firm, extremely stony, gritty silt loam with weak crumb structure; abundant, weakly weathered, angular greywacke gravels to large stones.

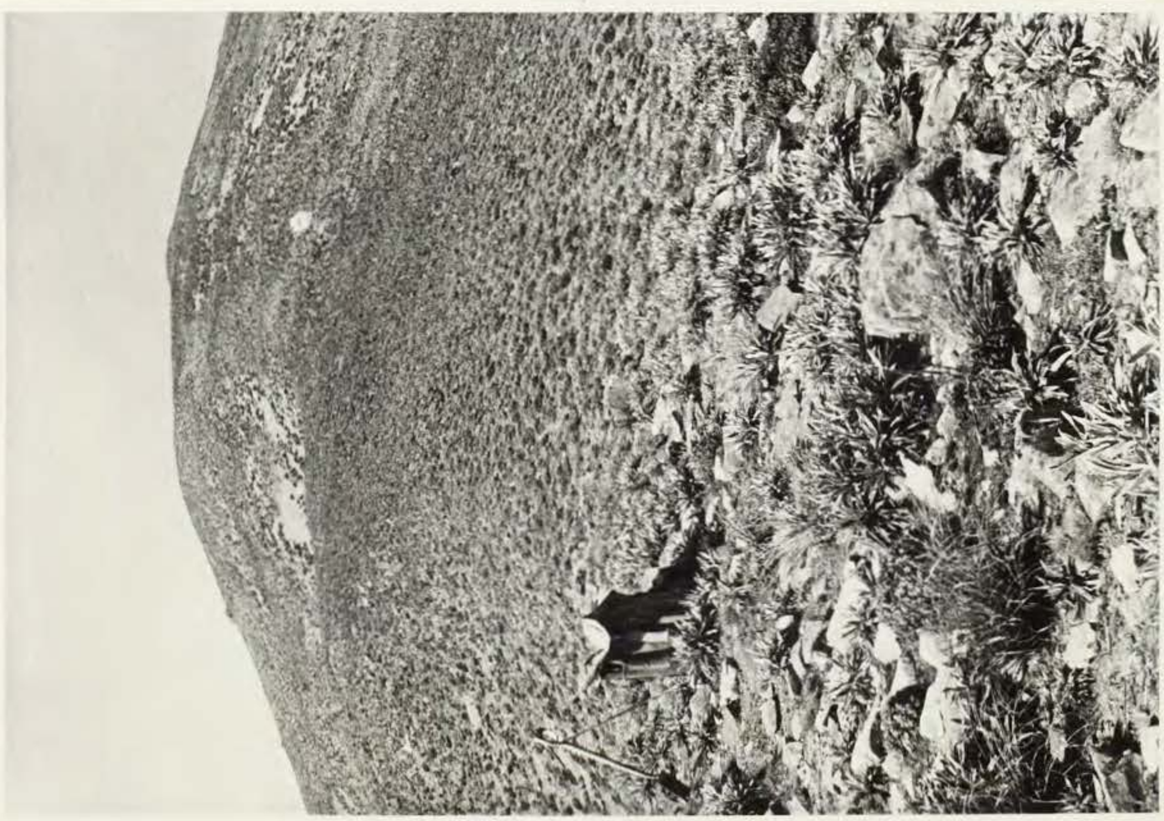
<u>Puketeraki stony silt loams</u> support a dominantly snow tussock community, and inter-tussock areas are often covered with a thin litter of tussock foliage. These soils tend to illustrate more markedly the effects of the drift regime as subsoils are usually less stony than the surface horizons. A typical profile is MC 69 (Appendix 1) which is abbreviated here as:

A	6"	dark greyish brown; very friable, stony, gritty silt loam with granular and crumb structure; common, angular, moderately weathered, greywacke gravels and small stones,
AB	4"	olive brown; friable, gritty silt loam with weak to moderate crumb and granular structure; few greywacke stones,
(B)	4"	light olive brown; friable, gritty silt loam with moderate nutty and crumb structure; few stones,
C	on	light olive brown; firm, extremely stony, gritty, heavy silt loam with weak nutty and crumb structure; abundant, moderately weathered, angular, greywacke stones and small boulders.

Stones are littered discontinuously over the surface of both of these soil types. Often small outcrops occur which are

Plate 12 - Puketeraki silt loam, hill phase. A thin stone-line, at the point of the knife is indicative of the composite nature of this soil.

Plate 13 - Surface of the Kaikoura hill soils (stony silt loam), looking towards Fiery Top along the south-eastern boundary. The depleted appearance of the snow tussock is due to recent burning.



responsible for wind erosion in that district (Raeside and Baumgart 1947). Strong reaction to the "allophane field test" (Fieldes and Perrot 1966) indicates as well, the presence of poorly ordered hydroxy-alumina material, probably in the form of allophane, in the subsoil of MC 69 and the (B) horizon of MC 84.

(d) Tekoa Series

i. Described elsewhere - environmental and morphological range - "The poor shallow soils formed from greywacke under beech forest on steepland between 1500 and 3500 ft are classed as Tekoa stony silt loam ... A profile under pasture on steep slopes ... is:

4" light-brownish-grey, friable, stony silt loam with a weak fine granular to single grained structure,

12" deep-yellow, slightly compact, stony clay loam on greywacke ..."

(Gibbs and Beggs 1953). These authors considered that this soil occurred at lower elevations below soils of the "Kaikoura loams". Vucetich (1969 p. 54) agrees with this position for the Tekoa soils in relation to the Kaikoura steepland soils.

A profile from under tussock grassland given by the Soil Bureau Staff (1968a) is of similar appearance, showing a dark greyish brown crumb and granular structured friable stony silt loam A horizon over a yellowish brown, blocky and nutty structured stony silt loam B horizon on greywacke rubble with silty matrix. These Tekoa steepland soils which were originally under beech forest are found on steep slopes over greywacke, greywacke solifluction debris and scree detritus, with some loess occur between 1200 and 3500 ft (Vucetich gives 3000 ft as upper limit) above sea level with annual precipitation of between 35" and 55".

A perusal of the Soil Bureau profile records, however, reveals that this simple straightforward concept has not been adhered to in grouping upland and high country steepland soils for the preparation of the maps for the Soil Survey of the South Island (Soil Bureau Staff 1968a). The records show, that in practice, two distinctly developed profiles have been grouped into the Tekoa set.

One group of soils fits the concept outlined initially by Gibbs and Beggs (1953) and detailed above. The second group of soils included within the Tekoa set are found on strongly to steeply sloping hillsides over greywacke colluvial debris and supporting a hard tussock-silver tussock matagouri vegetation association. They have 6" to 12" of very dark greyish brown to very dark brown gravelly or stony silt loam with friable consistence and moderate crumb structure as an A horizon. The B horizon is a brown to dark yellowish brown, very friable, stony silt loam with moderate crumb structure giving way between 15" and 20" to brown, loamy, greywacke colluvial gravels. These soils have been mapped within both the Tekoa steepland and Tekoa hill soils sets.

- <u>Discussion</u>

Consequently the problem arises as to what is the relationship between the true Tekoa soils of Gibbs and Beggs and the latter group above; and whether this latter group is in fact a Tekoa soil at all? Or should these soils with brown stony silt loam B horizons be designated as another soil series? Vucetich (1969 p. 54) has intimated that Tekoa steepland soils, formed under forest, are different from Tekoa soils under fescue tussock grassland. He noted marked A horizon differences but did not record differences in the B horizon which may have existed between soils on these two sites. Thus, it is not possible to say, that the two quite different soils recorded above result from

Table 10 - Chemical Variability of the Tekoa Set

Number of Analyses	Horizon	pH	% C	% N	C/N	CEC meq%	TEB meq%	BS %	Exchange cations meq% Ca^{++}	Mg^{++}	K^{+}	Na^{+}	
		5.8	8.5	0.35	25	28.4	12.4	74	8.8	2.2	1.25	0.30	Upper range
9	A	5.3	4.7	0.27	17	20.8	7.6	37	5.0	1.5	0.82	0.23	Medial values
		4.2	3.4	0.17	13	10.4	0.9	3	0.2	0.6	0.30	0.10	Lower range
		6.0	2.1	0.14	16	19.7	5.0	42	4.1	2.3	0.35	0.20	Upper range
9	B	5.4	1.7	0.12	14	14.4	2.5	17	1.4	0.4	0.19	0.13	Medial values
		4.9	1.0	0.06	10	11.8	0.6	4	0.2	0.1	0.06	0.10	Lower range
		6.4	0.8	0.08		20.5	3.7	47	3.3	1.0	0.20	0.15	Upper range
5	BC/C	5.7	0.75	0.07	9	13.7	2.6	19	1.8	0.5	0.15	0.12	Medial values
		5.2	0.7	0.06		9.2	0.3	11	0.8	0.2	0.11	0.10	Lower range

Source - Soil Bureau Records; S.B. Bull 27, Soil Bureau Bull. 9

different vegetation associations, although it is highly likely that this may be the case.

Soils similar to the latter profile above occur in the Mowbray area and they have been grouped with the Tekoa soils, on the basis of their lower slope occurrence adjacent to the Kaikoura soils, and their morphological similarity with the second kin of Tekoa grouping. There is, however, very little evidence to indicate a prior development under beech forest, and thus it is considered that they may be better assigned to another (probably new) soil series.

ii. <u>This survey - environment</u> - In the Mowbray area, soils of this form have been mapped as Tekoa steepland soil (stony silt loam). They occur on strongly to steeply sloping and steeply sloping hillsides, between 2500 and 3000 ft above sea level and over greywacke colluvial debris on greywacke or argillite. They support a broad-leafed snow tussock - matagouri - hard tussock association, are free draining and generally stones litter the surface. They occur on north to east facing aspects and give way on shaded aspects of the same ridges to Lookout soils.

- <u>Morphology</u>

The <u>Tekoa stony silt loam</u> has a dark greyish-brown, loose or very friable, stony silt loam, weak crumb and some granular structured A horizon. The B horizon is brown to yellowish brown in colour, has granular and crumb structure, and is usually a friable very stony silt loam. This horizon gives way at between 10" and 15" depth to a brown or olive brown, friable, very stony gritty silt loam C or BC horizon with weak crumb and granular structure.

Deeper profiles within these soils usually have a distinct boundary between the A and B horizons:

A	8"	dark greyish brown; very friable, stony silt loam with weak granular and crumb structure; common, angular, moderately weathered, greywacke gravels and stones,
(B)/BC	5"	yellowish brown; friable, very stony, gritty silt loam with weak granular and crumb structure; many, angular, greywacke gravels and stones,
C	on	olive brown; very stony, gritty silt loam with weak crumb and granular structure; abundant, angular, greywacke gravels and large stones;

- shallower profiles resulting from more intensive erosion of the upper layers usually have very thin A horizons over a transitional horizon above the B:

A	2"	dark greyish brown; loose, stony, gritty silt loam with weak crumb structure; common, angular, moderately weathered, greywacke gravels and stones,
AB	5"	brown; very friable, stony, gritty silt loam with weak to moderate granular, crumb and some fine nutty structure; common, angular, moderately weathered, greywacke gravels and stones,
(B)/BC	3"	yellowish brown; friable, very stony, gritty silt loam with weak granular and crumb structure; abundant, angular, greywacke gravels and stones,
C	on	olive brown, moderately compact, extremely stony silt loam with very weak crumb structure and abundant angular moderately weathered greywacke gravels and stones,
D		Stones forming an almost continuous phase below 14" depth.

Stones are scattered over the surface of these soils and in a few places form an almost continuous stone pavement.

- Chemistry and Mineralogy

Profile MC 77 which has been analysed, may not be completely typical of these soils because of its derivation from mixed greywacke and argillite colluvium over argillite. However, it does conform chemically with the medial range for the Tekoa soils and certainly within the very wide limits of chemistry revealed by Soil Bureau records for this set (Table 10). The very wide range of chemical conditions is no doubt due to the grouping of a wide range of not particularly similar profiles into this set.

Tekoa stony silt loam is only moderately acid, has a high level of "available" phosphorous, medium levels of exchangeable bases and a medium exchange capacity. Because of its shallow and stony nature this profile has medium levels of organic matter and high nitrogen content throughout the profile. This is a weakly weathered soil (Soil Bureau Staff 1968b) in which illite and interlayered chlorite dominate. Appreciable quantities of metahalloysite do occur but this material may have been derived from elsewhere rather than from weathering in place. A comparison of the Pa:Po:Pf as percentage of total phosphorous (Walker 1965), however, does tend to indicate much stronger weathering in these soils than the clay mineralogy reveals (see Figures 21, 22, 23, 26). An obvious explanation of this anomaly is that in fact this soil is a mixture of fresh detrital material and old weathered material. The source of the latter material, however, is not as apparent.

(e) Kaikoura Series

i. Described elsewhere - environmental range

By far the most extensive soil in the South Island high country

(Long 1966), this soil set has been recorded in many areas since the earliest surveys in high country areas. Gibbs et al (1945) recognised one type, the Kaikoura loam and three phases (two on a terrain basis and one on a subsoil colour basis). Gibbs and Beggs (1953) pushed for plurality in their definition of this soil noting that the, "... Kaikoura loams comprise a sequence of shallow silt loam, loam and sandy loam soils ...". The Soil Bureau Staff (1968a) grouped all Kaikoura soils in the Kaikoura steepland soil set, noting that this encompassed silt loams, sandy loams and stony loams. Vucetich (1969) emphasised the stony and eroded nature of the Kaikoura steepland soils, noting that bare screes and stone pavements were a common feature of this set. He also observed that soils on rolling and hilly lands which were equally susceptible to erosion when bared were also included with the Kaikoura steepland soil set.

The Kaikoura soils occur over greywacke and greywacke soliflfuct or talus detritus, sometimes with an admixture of wind-blown fines. It supports a snow tussock grassland association with subalpine scrub, and some beech forest in places, on steep to very steep hillsides with narrow rolling ridges where rock outcrops are common. They are found between 2500 and 5500 ft above sea level (Vucetich 1969 records 4000'-6000') and receive a precipitation of between 40 and 75 inches. Gibbs et al (1945) noted, however, that these soils do develop under a rainfall of 30" and added that, "In Canterbury, Kaikoura soils appear to need at least 40" of annual rainfall <u>or</u> an altitude of 3000 ft for their development ..."

- <u>Modal Profile</u>

The medial concept of a Kaikoura soil is an A horizon with between 5" and 8" of dark greyish brown or dark brown very friable silt loam with strongly developed crumb structure. The B horizon is a yellowish brown or brownish yellow friable silt loam with moderate nutty and rare crumb structure* and this gives way below 15-17" to light yellowish brown loose stony silt loam or sandy loam. Textures may vary to sandy loams or even loamy sands but stones are rarely encountered until the C horizon is reached, although both profiles quoted by Gibbs and Beggs (1953) exhibited stony B horizons, the Soil Bureau Staff (1968a) noted the occurrence of many truncated profiles capped with stone pavements and Vucetich (1969) considered that these soils were stony throughout the profile. This lack of stones in profiles on steep slopes is rather unusual when one considers that Gibbs et al (1945) considered that more than 73% of the Kaikoura loams on moderately steep slopes were subjected to moderate or stronger degrees of accelerated erosion. Of this percentage, 42.5% of these soils were either severely or extremely eroded.

ii. This survey - environment and morphology

In this context, in the Mowbray catchment, three soil types within the Kaikoura series have been identified. These are a stony silt loam, a very stony silt loam and a very stony sandy loam, all on steep lands; and a hill phase of the stony silt loam type, confined to rolling and hilly ridge crests. These may no doubt be considered to be moderately and severely** eroded phases of the Kaikoura loam(s) but they have been given type status rather than relating them as phases of a type (or types) which was not identified either within the Mowbray catchment or in adjacent areas.

* Nutty structure in the B horizon is at variance with commonly suggested occurrence of crumb structures throughout the profile of Kaikoura soils (Cutler pers comm). However, of 10 detailed profiles in Soil Bureau records only two had B horizons where crumb was the dominant structural shape.

** Estimation of degree of erosion is based on the method of Gibbs et al (1945 p.30).

In no case was the positive determination of a B horizon made; assuming a B horizon is normal for Kaikoura soils (Soil Bureau Staff 1968a p. 48). The profiles of these soils in the Mowbray catchment show either an A / AB / BC sequence or an A / AC sequence and in some cases an (A) / BC sequence, indicative of severe erosion, was observed.

The Kaikoura stony silt loam is found over greywacke colluvium consisting of a mixture of windblown fines and angular greywacke talus detritus. It occurs in locations of strongly to steeply sloping terrain, either adjacent to moderately steep and rolling ridge crests or in lower slope concave locations below steeply sloping hillsides. This soil type has a discontinuous cover of broad-leafed snow tussock, hard tussock, blue tussock, scattered matagouri and in places Celmisia sp. and Carmichaelia sp. A typical profile is:

A	6"	dark brown; very friable, stony silt loam with weak crumb structure; common, angular, weakly weathered greywacke gravels and stones,
AB	4"	brown to dark brown; very friable, very stony silt loam with moderate crumb and weak fine nutty structure; many, angular, greywacke gravels and large stones,
BC	on	brown; very friable, very stony silt loam with moderate crumb and weak fine nutty structure; abundant angular greywacke gravels, stones and boulders, becoming increasingly dominant below 13".

Profile MC 70 (Appendix 1) is another example of this soil although it is thicker than that quoted above.

On narrow rolling ridge tops, usually moderately and strongly sloping, one finds the hilly phase of this soil - Kaikoura hill soils (stony silt loams). Developing over shattered greywacke in place, or only slightly displaced by frost action, these soils support a broad-leafed and narrow-leafed snow tussock - hard tussock - blue tussock association with *Celmisia sp*. Cover is generally discontinuous and scattered stones, in lesser number than over the parent type, litter the surface. A typical profile is:

A	6"	very dark greyish brown; very friable, stony silt loam with moderate granular and crumb structure; common, angular, greywacke gravels and stones,
AB	6"	dark brown; very friable, stony silt loam with moderate to weak granular and crumb structure; common, angular, greywacke gravels and stones,
BC	4"	yellowish brown; very friable, very stony, gritty silt loam with weak nutty and crumb structure; many, angular, greywacke gravels and large stones,
Dr		giving way to continuous greywacke at 16" +.
		(stones are moderately weathered throughout)

In some locations this soil may be much thinner (see MC 83 Appendix 1) and a typical profile is:

A	5"	dark brown; very friable, stony, gritty silt loam with weak crumb and granular structure; common, angular, greywacke gravels and stones,
(B)C	3"	brown, very friable, very stony, gritty silt loam with moderate crumb structure; many angular, greywacke gravels and small boulders,
Dr		continuous finely jointed greywacke rock below 8".

Kaikoura very stony silt loam is found on strong to steeply sloping and steeply sloping hillsides in upper mid-slope to lower mid-slope locations. Rock outcrops are common and stones

Figure 9

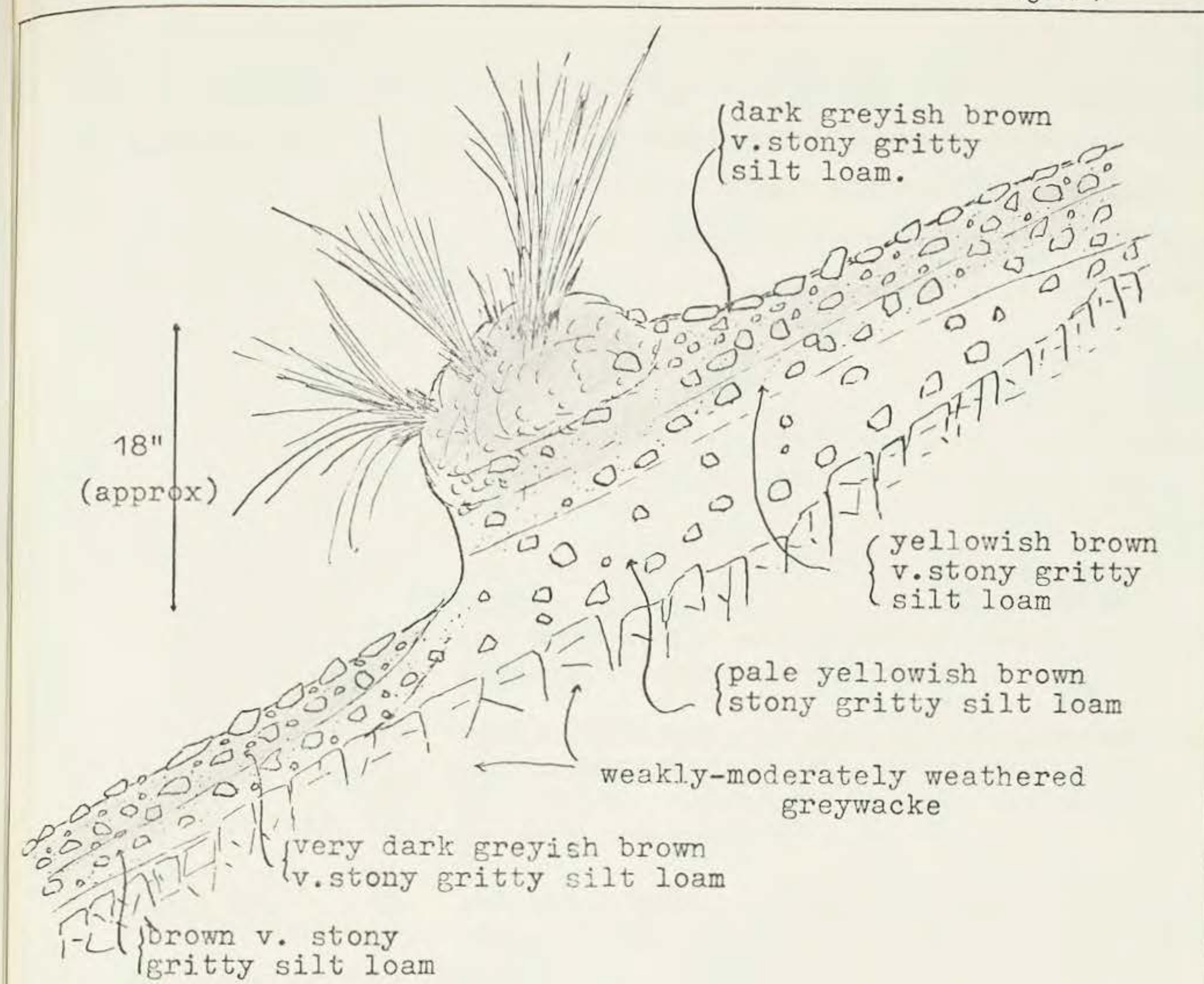


Diagram illustrates the range of soils included in the Kaikoura very stony silt loam type

Slope: 30°   Elevation: 4000'   Aspect: west

SOIL SEQUENCE THROUGH A SNOW TUSSOCK ON A STEEP SLOPE – KAIKOURA SERIES

(See also - Tussock Grasslands Res. Com 1954 p. 349; and Atkinson 1961 p.453.)

and small boulders litter the surface (Plate 14). Chionochloa flavescens and C. rigida associated with hard tussock and blue tussock are the common vegetation forms with minor occurrences of Celmisia sp. and matagouri (particularly at lower elevations). The range of profiles encountered is similar to that outlined above. A typical profile is:

A	5"	dark greyish brown; very friable, very stony, gritty silt loam with weak crumb and granular structure; many angular, greywacke gravels and stones,
AB	7"	greyish brown; very friable, very stony, gritty silt loam with weak to moderate crumb and weak granular structure; many, angular, greywacke gravels and stones,
BC	4"	light olive brown; very friable, extremely stony, gritty loam with very weak crumb structure; abundant, angular, greywacke gravels and stones,
C	on	yellowish brown, slightly compact, extremely stony, silty sandy loam with very weak crumb structure; abundant, angular greywacke gravels, stones and small boulders.

This profile occurs where a slight accumulation of material is found above individual tussocks (see Fig. 9). On the downhill side of the tussocks the profile is considerably thinner:

A	3"	very dark greyish brown; very friable, very stony, gritty silt loam with weak to moderate granular and crumb structure; many, angular greywacke gravels,
(B)C	on	brown; friable to firm, gritty silt loam matrix between abundant large stones and boulders.

The Kaikoura very stony sandy loam is a severely eroded soil similar to the shallower profiles of the stony silt loam and very stony silt loam types. It is found on steeply sloping hillsides in the region of rock outcrops. The surface is almost completely covered with stone pavement (Plate 15) but in places, snow tussock and Celmisia sp. afford some measure of stability to the shallow regolith. A profile is:

A	2"	dark brown; very friable, very stony, fine sandy loam with weak crumb and granular structure; many angular, greywacke gravels, stones and boulders,
(B)C	on	light yellowish brown; very friable; structureless, extremely stony, fine sandy loam; abundant, angular, greywacke gravels, stones and boulders.

As can be seen from the foregoing descriptions, it is very difficult to derive a composite, modal description for the Kaikoura soils as they occur in the Mowbray area. Basically, a dark brown, very friable, stony or very stony silt loam with weak crumb and granular structures overlies a brown to yellowish brown, very stony, very friable, silt loam with weak granular and crumb structure. This horizon rests on light yellowish brown C horizon of greywacke scree debris in a silt loam matrix. The C horizon probably represents the residual product of an earlier phase of weathering, the soils developing over it at present deriving the majority of their characteristics from downslope colluviation of eroded and eroding materials.

- Chemistry and Mineralogy

In the Mowbray, the Kaikoura stony silt loam is a moderately to strongly acid soil which has been very stongly leached. Soils of this type have medium levels of nitrogen due, in the main, to the medium levels of organic carbon spread throughout the profile. Similarly, exchange capacities are medium, but levels of exchangeable bases are generally low. As with the Tekoa soils, a wide

Plate 14 - Surface of the Kaikoura steepland soil (very stony silt loam) showing the accumulation of slope debris on the uphill side of a "cotton plant" (Celmisia spectabilis).

Plate 15 - Surface of the Kaikoura steepland soil (very stony sandy loam) showing the coarse nature of the slope debris which forms stone pavements on this soil. The snow tussock has been recently burnt.

range of chemical conditions have been accepted within the Kaikoura set and the analyses of the three profiles examined fall within the documented limits (Soil Bureau Records).

Interlayered hydrous micas and clay vermiculite (1) are the dominant crystalline clay minerals and indicate a weak to moderate amount of weathering (Fieldes and Taylor 1961). Illite and chlorite are subdominant and traces of gibbsite are also present. The presence of amorphous hydroxy-alumina, probably in the form of allophane was noted in the field.

(f) <u>Kirkliston Series</u>

i. <u>This survey - environment</u> - Kirkliston hill soils have been mapped in a very small area at about 3300 ft above sea level, almost on the western watershed of the area. In only this place in the whole of the Mowbray region has such an obviously well formed eldefulvic soil been recognised. One type, the Kirkliston silt loam has been identified. It occurs in a shallow almost level depression with moderately to steeply sloping peripheries, is developed from loess and fine slope-wash debris over deeply weathered greywacke under a precipitation of 30" to 35".

Under the system of classification employed in the Mowbray area, where the bulk of the soils have been correlated with the more eroded, more strongly leached variations of series mapped elsewhere, such a strongly developed upland yellow brown earth as that recorded (Appendix 1 - profile MC 42) has been difficult to reconcile with existing concepts.

\- <u>Morphology</u>

A profile of the <u>Kirkliston hill soil (silt loam)</u> is:

A	4"	dark brown; very friable silt loam with strong granular and fine nutty structure,
AB	3"	brown; very friable silt loam with moderate nutty and granular structure,
B_2	6"	brownish yellow; friable, heavy silt loam with moderate nutty and granular structure; rare, subangular, strongly weathered greywacke stones,
C	on	yellow; friable, heavy silt loam with weak nutty structure; rare greywacke stones.

Apart from a lack of crumb structure throughout the profile, this could be a typical profile for any of the eldefulvic soils discussed above. However, the modal concept of the upland and high country yellow-brown earths in the Mowbray area is one of a shallow and stony soil. As a consequence, rather than ally this soil with series already identified in the area, it was decided that this should be considered as a separate series, probably reflecting an earlier period in the genesis of the soils of the Mowbray and adjacent areas.

With, unfortunately, very little information available, it was decided to group these soils with the Kirkliston hill soils. Initially these soils had been grouped with the Benmore steepland soils which are closely similar to the Kirkliston soils but have a drier moisture regime. However, due to similarity of parent-material, topography - particularly their location in less exposed pockets on what was probably an old surface - moisture regime, texture, thickness of solum and depth to stones, these well developed eldefulvic soils in the Mowbray were regrouped with the Kirkliston soils. A scarcity of adequate documentation on both the Kirkliston and Benmore sets did nothing to help the correlation.

ii. Described elsewhere - Kirkliston hill soils are derived from loess over greywacke colluvium on rolling ridges and steep hillsides between 3000 and 5000 ft above sea level. Rainfall varies between 30 and 45" annually and the soils support a mixed cover of Chionochloa sp. with blue and hard tussock.

These soils occur in sheltered, less exposed sites on the broad upper surfaces of the Hawkdun, St Marys and Kirkliston ranges and the Hunter Hills and in the Mowbray area they exhibit a similar topographic occurrence. Their occurrence may in fact mark the last remnants of an old dissected peneplain although Gair (1962) made no mention of such on the western side of the Mowbray Fault. It is interesting, however, to note the occurrence of stone streams (Gair, 1962, which are the "stone drains" of McCraw 1959), on the western side of the watershed in this area (i.e. outside the Mowbray catchment). Certainly in the present location, it is quite conceivable that these soils were part of a surface which was continuous with Blue Mountain and regions further east. An interesting study could be the investigation of areas considered by Gair as "exhumed peneplain surfaces" for other occurrences of this soil.

2. SOILS ARRANGED PEDOLOGICALLY

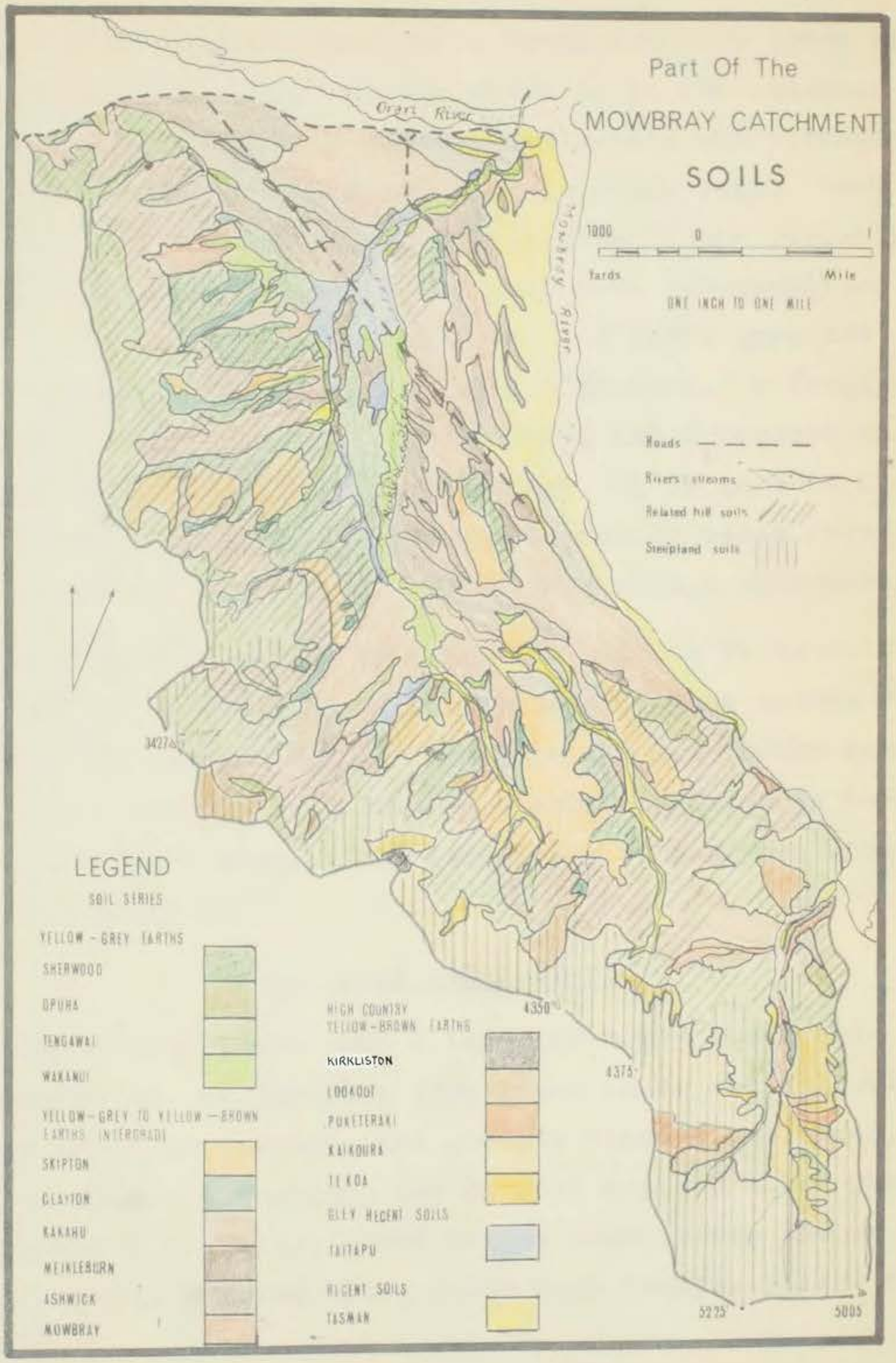
In 1959 (Taylor et al 1959) a first subdivision of the main zonal soil groups of New Zealand on a moisture basis appeared. Previously soils had been subdivided at the lower levels on the basis of either degree of leaching, stage of weathering, degree of gammation, intensity of gleying or the nature of melanization or certain combinations of any two of these criteria (Taylor 1948).

Taylor and Pohlen (1962 p. 44-46) suggested a more sophisticated set of moisture status differentiating classes than those initially proposed by Taylor et al (1959). These moisture classes have found wide acceptance and have been used in the classification of the soils of the South Island (Soil Bureau Staff 1968a).

Annual moisture budget and the nature of the parent material (as influenced by the drift regime) are considered to be the two major factors in the formation of the soils of the Mowbray area. Consequently, a modified version of the classification of the soils of the South Island (Soil Bureau Staff 1968a) has been used. Less emphasis has been placed on landform because if serves as the basis for the common classification employed above. Table 11 outlines the groupings employed and also indicates correlations with the South Island soil sets.

Moisture classes (Taylor and Pohlen 1962 p. 44-46) have been assigned to each series. The assigned classes in some cases are at variance with those proposed for the relevant parent soil set by Soil Bureau Staff (1968a). The assigned moisture class for each South Island set is based on a number of observations over a wider range of climatic and soil characteristics than those characterising the corresponding series mapped in the Mowbray catchment. Consequently, a class assigned during the present survey may be just one end of the range of moisture conditions influencing a particular soil, the quoted class (Soil Bureau Staff 1968a) representing the average moisture class observed over a greater range of environmental and soil conditions. Classes assigned to series in the Mowbray catchment are based on the Thornthwaite P-E calculations (Table 5) and discussion in Chapter VI, section 3. The moderating influences of texture, topography and soil depth have also been considered in these assessments.

Fig.10


Part Of The
MOWBRAY CATCHMENT
SOILS
Orari River
Mowbray River
1000
0
1
Yards
Mile
ONE INCH TO ONE MILE
Roads
Rivers streams
Related hill soils
Steepland soils
3427
4350
4375
5225
5005
LEGEND
SOIL SERIES
YELLOW - GREY EARTHS
SHERWOOD
OPUHA
TENGAWAI
WAKANUI
YELLOW-GREY TO YELLOW-BROWN EARTHS INTERGRADE
SKIPTON
CLAYTON
KAKAHU
MEIKLEBURN
ASHWICK
MOWBRAY
HIGH COUNTRY YELLOW-BROWN EARTHS
KIRKLISTON
LOOKOUT
PUKETERAKI
KAIKOURA
TE KOA
GLEY RECENT SOILS
TAITAPU
RECENT SOILS
TASMAN

(1) Yellow-Grey Earths and Related Soils

- on Loess

These are moderately deep soils developed from loess and forming over an older loess deposit which is in the position of a C horizon. They occur over gently, moderately and strongly sloping hillsides and on low level and low angle fans. Very dark greyish brown silt loam topsoils overlie firm, light yellowish-brown heavy silt loam subsoils which show weak sub-gammation. The compact, C horizon impedes drainage, and light grey and orange mottles may be seen in the lower B horizon. A fragipan exists in these soils but as it constitutes the C horizon which is considered to be an older loess deposit, it is more in the nature of a "fossil" fragipan than one currently being formed. Soils of the Sherwood and Opuha series fall within this group.

Sherwood series on the more exposed aspects falls within the limits of the subhygrous moisture class. Opuha series which occupies more sheltered aspects, does not dry out to the same extent as the Sherwood series and on a moisture bases is between subhygrous and dry hygrous. For simplicity it has been shown as subhygrous on Table 11.

- on Loess and Colluvium

Developed from loess over a layer of mixed loess and colluvial material, or directly from mixed loess and colluvium, these soils occur on strongly and steeply sloping hillsides. They are found at higher elevations and on more exposed sites than yellow grey earth to yellow brown earths intergrade, and at lower elevations on well drained sites below high country yellow brown earths.

Table 11 - Common Genetic Classification of the Soils of the Mowbray Catchment

		Correlation with Soils of South Island (Soil Bureau Staff 1968a)
YELLOW-GREY EARTHS		
(with related hill and steepland soils)		
subhygrous	- on loess	
	- Sherwood series	Sherwood
	- Opuha series	Opuha
	- on loess and colluvium	
(related steepland soils)		
	- Tengawai series	Tengawai
dry-hygrous	- on loess and alluvium	
	± Wakanui series	Wakanui
YELLOW-GREY EARTH TO YELLOW-BROWN EARTHS INTERGRADE		
(with related hill and shallow and stony soils)		
dry-hygrous	- on loess	
	Skipton series)	
	- on loess and colluvium)	Skipton
	Clayton series)	
	Kakahu series	Kakahu
subhygrous	- on loess and alluvium	
	Meikleburn series)	
(related shallow and stony soils)	)	
	Ashwick series)	Ashwick
	Mowbray series)	
UPLAND AND HIGH COUNTRY YELLOW-BROWN EARTHS		
(with intergrades to skeletal soils and related hill and steepland soils)		
dry-hygrous	- on loess and colluvium	
	Kirkliston series	Kirkliston
hygrous	- on loess and colluvium	

cont.

(related steepland soils)

		Lookout series)	Puketeraki
		Puketeraki series)	
dry-hygrous	-	on colluvium	
		Tekoa series	Tekoa
		Kaikoura series	Kaikoura
GLEY RECENT SOILS			
	-	on alluvium	
		Taitapu series	Taitapu
RECENT SOILS			
	-	on alluvium	
		Tasman series	Tasman

They have dark greyish brown silt loam topsoils which grade into firm light yellowish brown stony silt loams. The subsoil becoming increasingly stony, with only weakly argillised greywacke colluvial debris, with depth. Tengawai series belongs to this group.

Tengawai series which occurs at higher elevations than yellow-grey to yellow-brown earths intergrade, and receives a similar or slightly higher precipitation, is considered to belong to the subhygrous class. Greater exposure and greater runoff, due to the steeper slopes and less dense vegetation, means that precipitation is less effective than at lower altitudes. Runoff and subsurface flushing from Tengawai sites also helps to maintain a more uniform moisture balance in the yellow-grey earth to yellow-brown earths intergrade which occur on mid-slope and lower-slope locations.

- <u>on Loess and Alluvium</u>

Occurring on low terraces adjacent to slow flowing streams and along the beds of old stream channels the Wakanui series has developed from a mixture of rewashed loess and fine alluvium. These soils have very dark greyish brown A horizons over grey or pale yellow subsoils, which have silty clay loam texture and are mottled in yellow brown and brownish grey. The subsoil is usually firm becoming quite compact on drying and displays weak sub-gammation. The underlying C horizons are greyish with yellow mottles and of lighter, often gravelly texture.

Although these soils dry out seasonally, their low-lying sites and a water table at shallow depth below the solum means a greater potential for maintenance of soil moisture than the other yellow-grey earths in the Mowbray area. This series has been grouped with the dry-hygrous moisture class.

(2) <u>Yellow-Grey Earth to Yellow-Brown Earths Intergrade and Related Soils</u>

Soils grouped as yellow-grey earth to yellow-brown earths intergrade also fall into the dry-hygrous moisture class. These soils are never below wilting point but may be below field capacity for up to five months annually. The impeded drainage and better moisture retention of this group, plus the higher rainfall and subsurface flushing which they experience, are factors contributing to their classification as dry-hygrous soils. Related shallow and stony soils and to a less degree, moderately deep soils from loess and alluvium, because of coarser textures and rapid through drainage (Taylor and Pohlen 1962 p. 46) belong to the subhygrous class.

- <u>on Loess</u>

The dry-hygrous soils are separated from their yellow-grey earth counterparts by a higher annual moisture content as evidenced by stronger mottling and weaker clay illuviation in the B horizon. Colours tend to be slightly yellower although the Munsell colour charts are not sufficiently discriminate to show this difference.

They are deep soils with very dark greyish brown silt loam topsoil over a firm, light yellowish brown, mottled silt clay loam B horizon which may contain iron and/or manganese concretions. A fragipan occurs in the position of a C horizon and displays vertical light grey and orange streaks. The Skipton series falls within this group.

- on Loess and Colluvium

Occurring on easy rolling to moderately steep terrain, these soils range from imperfectly drained heavy soils to well drained soils with stony subsoils. The imperfectly drained soils have dark greyish brown silt loam topsoils which poach badly when wet. They overlie pale yellow and light grey, gleyed B horizons which are orange mottled, firm, silty clay loams. They have a compact similarly coloured fragipan in the position of a C horizon and thin manganese coatings commonly line vertical channels and cracks in this horizon. These soils show moderate gammation and have been called Clayton series during this survey. They have stony subsoils in moderately sloping sites and for this reason have been placed in this subgroup.

Kakahu series occurs on moderately and strongly sloping hillsides and is formed from loess of variable thickness over mixed loess and colluvial materials. Soils of this series have thick sola, the lower part of which is usually a stony silt loam of stony clay loam of light yellowish brown colour. The degree of argillisation of these greywacke fragments varies considerably as they may be derived from freshly broken rock or from an old preweathered colluvial deposit. The underlying C horizon which is often moderately compact may be considered as a "stony loess pan" equivalent to the fragipan in soils on older loess. These soils show irregular sub-gammation on drying.

- on Loess and Alluvium

Loess of variable thickness has coated the alluvial fans of the Orari and Mowbray rivers and the Meikleburn stream. The loess is of a coarser nature than that found on the adjacent hillsides and has to a large extent been incorporated into the original alluvial fan material by biological activity. The moderately deep Meikleburn soils with light yellowish brown friable stone free B horizons, because of the effect of available moisture on these finer textures in relation to the weathering of components, are closer in form to the yellow-grey earths than to the yellow-brown earths.

The Mowbray and Ashwick series, on the other hand have greater affinity with the yellow-brown earths despite their occurrence in a yellow-grey earth zone. Their free drainage associated with their coarser textures (Soil Bureau Staff 1968a) is responsible for their yellow brown character. These soils have dark greyish brown topsoils which have granular and crumb structures and are often stony. The subsoil is yellowish brown, has silt loam or sandy loam textures and is almost always stony with only very weakly argillised alluvial gravels. The underlying C horizon material is usually a very stony olive brown sandy loam. B horizon development is not as distinct as in the better developed, deeper finer textured counterparts on the fan and terrace surfaces.

(3) Upland and High Country Yellow-Brown Earths

- on Loess and Colluvium

These are either moderately deep fine textured soils developed over deeply weathered loess and colluvium, which fall into the dry-hygrous moisture class (Soil Bureau Staff 1968a), or are developed over only weakly weathered mixed loess and colluvial deposits under a moister (hygrous) regime, on sheltered southern or western aspects.

Kirkliston series occurs on an ancient surface of soil formation. It has a well developed, brownish yellow, heavy silt loam B horizon, which overlies a yellow, stony, heavy silt loam C horizon which contains strongly argillised greywacke fragments. This series has gradational texture profiles, probably as a result of clay illuviation.

The moister soils on steep slopes developed over intimately mixed loess and colluvial slope detritus have dark greyish brown, often stony, silt loam A horizons. A weakly formed B horizon with light yellowish brown to olive brown colour and usually a stony silt loam texture occurs below 8" to 10". In many cases this soil rests on a firm light yellowish brown, slightly stony silt loam which represents a buried B horizon of a former soil, developed during a period of greater stability. The topsoil has moderately developed crumb and granular structures while the subsoil exhibits moderately to weakly developed nutty and crumb structures. This subgroup includes soils of the Lookout and Puketeraki series.

- <u>on Colluvium</u>

These are generally shallow soils which are derived from predominantly greywacke colluvial material. They occur on steeply sloping hillsides and on narrow ridge crests. They have coarser textures than other high country yellow-brown earths in the area, have a poor vegetative cover, and are moderately to strongly eroded. They have only very weak profile development and on many sites intergrade to skeletal soils. Because of their coarse textures and consequent rapid through drainage, they are considered as members of the dry-hygrous moisture class. In wetter years, however, they are probably rarely if ever below field capacity, but during dry years moisture levels fall below field capacity during late summer.

Dark brown, stony topsoils overlie brown to yellowish brown, often extremely stony subsoils. Topsoils have weakly developed crumb and granular structures, become very light and fluffy on drying and usually have a high organic matter content. Subsoils, usually designated as BC horizons, are of friable consistence and usually have weakly developed crumb and fine nutty structures. These are the soils of the Tekoa and Kaikoura series, in the Mowbray area. A hill phase of the Kaikoura series, occurring on the moderately sloping narrow ridge crests at high altitude, has been identified. Strictly speaking, this phase is developing over weathering bedrock in place, but because of its morphological similarities with the parent Kaikoura series it is included with the description of this subgroup.

(4) Gley Recent Soils

Gley recent soils occur on or adjacent to floodplains where, in the past, they have been subject to periodic flooding. In the Mowbray area the Taitapu series is the only member of this group. This soil is poorly drained and in the past has received additions of flood silts during periods of heavy rain. Recent attempts at drainage, aided by the underlying gravels and sands has considerably reduced the waterlogged initial nature of this soil.

Such soils have a very dark grey, turfy, silt loam A horizon, the lower part of which is characterised by rusty mottlings adjacent to root channels. The underlying (B) G horizon is strongly gleyed and is usually greenish grey to pale olive brown in colour. Textures range from silt loam to heavy silty clay loams, structures are commonly coarse and blocky and orange and yellow mottling is prevalent.

(5) Recent Soils

Recent soils from riverine alluvium are widespread over the lower floodplains and levees of the Orari and Mowbray rivers and on terraces adjacent to the mid-portion of the Meikleburn stream. They are derived almost completely from riverine alluvium and seem to be contributing loess, through the agency of wind erosion, rather than receiving such additions, as is the case on many recent soils (Soil Bureau Staff 1968a).

Tasman series is generally shallow and stony. Soils of this series have dark greyish brown topsoils which have moderately to weakly developed granular and crumb structures. AC horizons below about 6" are invariably stony and show very weakly formed granular and crumb structures. These horizons are brown or olive brown in colour and usually give way to similarly coloured horizons of river sands and gravels at 9" to 12" depth.

CHAPTER VI

CLASSIFICATION

Soil classification is the fundamental vehicle of the soil scientist. In order to logically disseminate information obtained during his investigations, the soil scientist must first resort to generalisations concerning particular groupings of soils. Such groupings may be based on similarity of appearance, properties, history, constitution, use potential etc. But, whatever the basis, such groupings are above all part of a system of classification. And it is by way of this system that the soil scientist imparts the knowledge he has acquired.

The history of soil classification in New Zealand has been summarised by Pohlen (1962). The major step in the development of the New Zealand classification was the appearance of Taylor's (1948) "genetic classification" of soils (called "common genetic classification" by Fieldes 1968). The basic concepts behind the evolution of the common genetic classification of New Zealand soils have been outlined by Pohlen in N.Z. Soil Science Society 1964 pp. 7-10.

(1) The Technical Classification of New Zealand Soils

The "technical genetic classification" of New Zealand soils, so called by Fieldes (1968) to differentiate it from the earlier "common genetic classification", was evolved primarily to give precise meaning to the then commonly applied terms which resulted from the widespread usage of Taylors (1948) classification. Such definition apparently was required to delimit groups which, although separated by Taylor, had lacked precise definition.

Pohlen (1962) a co-author of the technical genetic classification failed to establish a single reason for this classification and argued around the point with verbose statements such as, "the pedologist perforce establishes his classes in precise technical language and, in order to allow the classification to be used freely, translates to the common names which are well known to the layman and are free from technical jargon".

In two words, however, the technical genetic classification may be differentiated from the common genetic classification in that it is <u>comprehensively definitive</u>. Soils are defined in terms of their basal form, latitudinal and altitudinal zone of occurrence (which bears climatic conotation), degree of weathering or influence of the drift regime, the kind and degree of illuviation, gleying or accumulation, their state of enleaching, the nature of their parent material and its degree of weathering and the texture of the surface horizons (Pohlen 1962, Taylor and Pohlen 1962, Soil Bureau Staff 1968b).

The soils of the Mowbray catchment have been grouped according to the technical genetic classification (table 12) and their detailed technical terminology according to this classification is outlined in Appendix 1. Although Taylor (1948) intended the common genetic groupings to be distinguished on the basis of soil forming processes (Pohlen in N.Z. Soil Science Society 1964) the application of his classification, particularly on soil maps, has tended to become distinctly terrain biased (Taylor 1948, Gibbs and Beggs 1953, Raeside et al 1959, McCraw 1964, Kear et al 1967, Soil Bureau Staff 1968a, b). The technical classification in fact, as intended, achieves the early aim of Taylor. Soils are grouped together on the basis of the intensity of influence of soil forming processes on their genesis.

Table 12 - Technical Classification of Soils of the Mowbray Catchment

PALLIFORM SOILS:	
(a) Pallic soils	
- moderately to strongly enleached	Opuha series
- very strongly enleached	Sherwood series
(b) Madenti-pallic soils	
- weakly enleached	Wakanui series
(c) Fulvi-pallic soils	
- moderately enleached	Skipton series
- very strongly enleached	Meikleburn series
(d) Madenti-fulvi-pallic soils	
- moderately enleached	Clayton series
(e) Lithi-pallic soils	
- strongly enleached	Tengawai hill soils
(f) Clini-pallic soils	
- strongly enleached	Tengawai series
FULVIFORM SOILS:	
(a) Palli-fulvic soils	
-moderately to strongly enleached	Kakahu series
- strongly enleached	Ashwick series
- very strongly enleached	Kakahu hill soils
(b) Eldefulvic soils	
- very strongly enleached	Puketeraki series
and - weakly clay illuvial	Kirkliston series
(c) Lithi-eldefulvic soils	
- very strongly enleached	Lookout series
	Kaikoura hill soils
(d) Clini-lithi-eldefulvic soils	
- moderately enleached	Tekoa series
- very strongly enleached	Kaikoura series

Cont.

SKELIFORM SOILS:

(a) Luvic soils

- moderately to strongly enleached — Tasman series

(b) Madenti-luvic soils

- very weakly enleached — Taitapu series

Thus different soils which have a similar history of development are grouped together into a single subclass. For example, the Skipton and Meikleburn series, or the Kirkliston and Puketeraki series. By the same token soils within one set which have different genetic histories are separated, thus giving a greater insight into their formation, form and use potentiality not evident under the common genetic classification (e.g. the Tengawai set).

For these points alone, not to mention the strong genetic bias and high level of definity, the easy positioning of intergrades and easily applicable sectionalised nomenclature, the technical classification should supersede the common genetic classification and become the common language of all soil users.

(2) <u>The Constitutional Classification of New Zealand Soils</u>

Fieldes saw a greater need for separation of soils on the basis of their constituent clay minerals (Fieldes 1958, in Taylor and Pohlen 1962, Soil Bureau Staff 1968b). In the initial stages of the evolution of divisions based on soil constituents it was proposed that, mineral-denoting prefixes be introduced at category III level of the technical classification (Pohlen 1962).

Later (Fieldes 1964 and 1968) these phasic subdivisions were extended to form a separate grouping of soils into classes determined by the nature and form of their principal clay sized (less than 2 microns) mineral constituents. This was termed "constitutional classification".

Two basic principles were deemed to show the need for the consideration of constitution in soil classification:

"(a) soils of very different constitution are different and will behave differently,

(b) soils of similar constitution are similar. They may or may not behave similarly depending upon their (morphological arrangement) and their environment." (Fieldes 1964, 1968)

It was considered also, that many soil properties were dependent on constitution e.g. pH, base saturation, biological tolerances and certain fundamental chemical and physical properties. With this background, Fieldes proposed a classification of soils based on the nature of the dominant inorganic clay constituent of the topsoil (A horizon). Ten main soil classes were proposed with the opportunity to expand into additional classes should the occasion arise. In Table 5 (Fieldes 1968) indicated the constitutional class and subclass of a number of soils. He did not, however, explain how one proceeds to establish the lower levels of this classification, but one assumes that if one keeps prefixes in order of decreasing dominance of clay minerals one must eventually end up with the ultimate identification of a soil type. For example, a topsoil which has the following constitution:

Chlorite	6%
Interlayered chlorite	10%
Illite	35
Interlayered hydrous mica	4
Clay-vermiculite (1)	8
Clay-vermiculite (2)	15

Quarts	3%
Feldspar	2

(from Soil Bureau Staff 1968b, part 3, p. 113)

would be an "illosol", subclass "vermo-Illosol". If in addition it contained say 7% montmorillonite, it could then be subdivided at a lower level as a "monto-chloro-vermo-Illosol". Thus, while at present the system is only loosely defined, it is potentially an open system of classification; like the technical classification; and new subclasses and lower levels of separation can be established at will to meet the requirements of expanding knowledge and experience.

Similarly, it has distinct advantages in that it operates independently of climatic data and soil moisture characteristics, facts which are often unavailable or inadequately documented for many regions. It has distinct genetic conotation and can be used to show evidenceof polygenesis in soils, reasons for the anomalous behaviour of certain series, sets, or suites, and the position of intergrade soils between one group and another (Fieldes 1968).

It is of limited use at present, however, because:

(a) comprehensive mineralogical data is available for only a limited number of soils, although Fieldes (1968) notes that inferences may be made about soils for which there is no mineralogical data, merely by direct examination of the soil (body ?),

(b) as a continuation of (a) it is of little practical use to the man in the field because of the inability to gain constitutional information for the vast number of soils which he examines annually,

(c) there is at present very little attempt to correlate soil classes and subclasses with the categories and levels of the technical and common genetic classifications,

Table 13 - Tentative Constitutional Assessment[1] of Selected Mowbray Area Soils by Horizons

No.	Soil	A Horizon	'B' Horizon	C Horizon	Dominant Average of all Horizons	Proposed Grouping	
53	Sherwood	illo-1 Vermosol	hallo-vermo-chloro-Illosol	2 vermo-Illosol	vermo-chloro-Illosol	chloro-Illosol	on 2 Vermo-Illosol
79	Opuha (hill)	chloro-Illosol	hallo-chloro-Illosol	hallo-2 Vermo-Illosol	hallo-vermo-chloro-Illosol	chloro-Illosol	on 2 Vermo-Illosol
44	Tengawai (hill)	chloro-Hallo-Illosol	chloro-Hallo-Illosol	1 vermo-Hallo Illosol	vermo-chloro-Hallo-Illosol	Hallo-Illosol	
72	Tengawai (hill)	vermo-chloro-Hallo-Illosol	hallo-chloro-Illosol	hallo-1 vermo-Illosol*	vermo-hallo-chloro-Illosol	chloro-Illosol	on 1 vermo-Illosol
85	Tengawai (hill)	vermo-chloro-Illosol	hallo-illo-1 Vermosol	vermo-illo-Chlorosol	vermo-chloro-Illosol	chloro-Illosol	on illo-Chlorosol
89	Skipton	chloro-vermo-Hallo-Illosol	vermo-chloro-hallo-Illosol	hallo-Illo-2 Vermosol	hallo-chloro-2 Vermo-Illosol	hallo-Illosol	on Illo-2 Vermosol
81	Kakahu (hill)	vermo-Chlorosol	vermo-Illo-Chlorosol	vermo-Illo-Chlorosol	vermo-illo-Chlorosol	illo-Chlorosol	
28	Kakahu	hallo-Chloro-Illosol	hallo-Chloro-Illosol	hallo-2 Vermo-Illosol	hallo-chloro-Illosol	Chloro-Illosol	on 2 Vermo-Illosol
70	Kaikoura	1 Vermo-Chlorosol	illo-Chlorosol**	illo-chloro-1 Vermosol**	1 vermo-Chlorosol	1 Vermo-Chlorosol	on chloro-1 Vermosol
83	Kaikoura (hill)	Chloro-1 Vermosol		1 Vermosol**	illo-chloro-1 Vermosol	Chloro-1 Vermosol	on 1 Vermosol
41	Kaikoura (hill)	Chloro-1 Vermosol	1-2 Vermosol	2 Vermosol**	2-1 Vermosol	Chloro-1 Vermosol	on 2 Vermosol
77	Tekoa	hallo-chloro-Illosol		hallo-chloro-Illosol	chloro-hallo-Illosol	chloro-Illosol	
64	Lookout	vermo-chloro-Illosol	2 Vermo-Illosol*	2 vermo-Chloro-Illosol**	chloro-Vermo-Illosol	chloro-Illosol	on 2 Vermo-Illosol
69	Puketeraki	chloro-1 Vermosol	vermo-Chlorosol**	illo-chloro-1 Vermosol**	1 Vermo-Chlorosol	chloro-1 Vermosol	
84	Puketeraki (hill)	chloro-illo-2 Vermosol	monto-illo-1 Vermo-Chlorosol**	chloro-monto-1 Vermosol on illo-Montosol*	monto-vermo-illo-Chlorosol	illo-2 Vermosol	on illo-Montosol

Reaction to allophane field test: * weak, ** strong, blank not determined

1 This assessment after Fieldes (1964, 1968) is only based on estimated quantitative percentages of crystalline clay minerals as assessed by the method of Claridge (1969). Quantitative estimates of the content of amorphous colloids have not been determined, and along with gibbsite, whose presence only has been noted, may influence final groupings.

(d) it has no morphological aspect which limits its use by the man in the field, and this is the level at which it should in fact be directed as he is the person who must interpret classification terminology into the generalisations (and specific statements) which are required by the land user,

(e) as it is based on only a limited set of properties of a solum it may have difficulty standing on its own.

It was decided, however, to test the practicability of the constitutional classification, and those soils of the Mowbray area for which mineralogical data is available have been classified accordingly. In doing this it was decided to compare the classification obtained by an examination of the average clay mineralofical composition of the whole profile with similarly deduced classifications for the three main diagnostic horizons. The conclusions reached are summarised in Table 13. In addition a proposed classification of each soil has been established. (Tables 13 and 14).

By extending the constitutional assessment beyond the topsoil (of Fieldes - A horizon in this document) it has been possible to show evidence of polygenesis in a number of soils. This is in keeping with the genetic history of the soils of the Mowbray area proposed in earlier sections (i.e. "later Quarternary History" and "Pedomorphic Surfaces" Chapter IV 5/6). Such data is revealed in the "proposed grouping" column of Table 13.

The proposed constitutional classification has been restricted to the assessed nature of the A horizon in keeping with groupings proposed by Fieldes (1968). Metahalloysite was found in a number of soils (see Appendix 1), but its genetic significance is not fully understood and will be discussed later. Because of second and third order interference by 10 Å and 14Å minerals it was not

Table 14 - Constitutional Classification of Some Soils of the Mowbray Catchment

ILLOSOLS	
chloro - Illosols	Sherwood silt loam Opuha silt loam (hill phase) Tengawai stony silt loam (hill phase) Lookout steepland soil (stony silt loam)
hallo - Illosols	Skipton silt loam
Hallo - Illosols	Tengawai silt loam (hill phase)
VERMOSOLS	
chloro - I. Vermosols	Kaikoura stony silt loam (hill phase) Puketeraki steepland soil (stony silt loam
I. Vermo - Chlorosols	Kaikoura steepland soil (stony silt loam)
illo - 2 Vermosols	Puketeraki stony silt loam (hill phase)
CHLOROSOLS	
illo - Chlorosols	Kakahu silt loam (hill phase)
Chloro - Illosol	Kakahu silt loam

possible to estimate quantitatively the amount of gibbsite present in many soils. Its presence, however, was confirmed by D.T.A. and I.R. techniques. Similarly, amorphous hydrous colloids were destroyed during the preparation of samples for X-ray diffractometry (Claridge 1969 p. 16), and it has only been possible to indicate their presence following application of the "Allophane Field Test" (Fieldes and Perrott 1966). Consequently, it must be realised that Table 14 represents only an approximate classification of some of the soils of the Mowbray and as such should be viewed merely as the result of an interesting academic exercise.

CHAPTER VII

SOIL VARIABILITY

In conducting a soil survey, the pedologist must first identify the taxonomic units of his classification. By doing this he separates the soils at the lowest possible level of differentiation on the basis of profile characteristics of significance for soil genesis. During the production of a soil map, taxonomic units may be grouped together to form mapping units which show the greatest amount of detail required by the demands of the survey and limited by the scale of the map.

The soil type is the basic unit of soil mapping in New Zealand (Taylor and Pohlen 1962 p. 135). In general the taxonomic entities identified in the field are equated with soil types, (USDA 1951 p. 277) such taxonomic units considered as being similar to the concept of the pedon (USDA 1960) with clearly defined limits. However, it would appear from the literature, that in New Zealand, attempts are rarely made to characterise the morphological range of soil types, particularly in relation to the pedon concept.

Why documentation on soil types lacks such definition has become obvious following studies in the variability of soils within what should be, on a detailed soil map, homogeneous units. Very detailed examination of a number of small, one acre, quadrats in areas of apparently homogeneous soil type have revealed the partial extent of the complexity which exists.

Such small studies were undertaken, not to attempt to statistically analyse the extent of the variation from a central concept, which has been the aim of workers such as Beckett (1967)

PLATE 16. High angle oblique aerial photograph of the Mowbray fan and the upper Meikleburn fan in the centre middle distance. Southern and western boundaries of the catchment on the skyline.

Photo. P.J.Tonkin

PLATE 17. Low angle oblique aerial photograph of the lower Mowbray fan and Mowbray River.

Photo. P.J.Tonkin.

PLATE 18. Low angle oblique aerial photograph of the Orari fan and the Orari River . Meikleburn homestead and the Meikleburn stream are seen in the bottom left corner.

and Protz et al (1967), but to demonstrate:

(a) the nature of the various phases and sub-types likely to be encountered within any homogeneous mapping unit, and

(b) the difficulty of mapping precisely the soil type in order to conform with the requirement that no more than 15% total of other basic mapping units be included within the boundaries of that so named, and delimited, unit.

A little of the expected complexity of the soil pattern, particularly on the fans and terraces, may be apparent on the stereograms, Plates 1, 2. Such apparent complexity becomes more obvious on the high angle oblique photograph Plate 16 and startingly real on the low angle obliques Plates 17 and 18 of the lower Mowbray and Orari fans. Quadrats 1, 2 and 3 (Figs 11, 12, 13) were examined in order to assess variability within recent stony and sandy soils, recent imperfectly and poorly drained soils and loess derived soils, on the fans and flood plains. In particular these Quadrats illustrate the variation likely to be encountered in the soil types; Tasman sandy loam, Taitapu silt loam and Sherwood silt loam.

Small inclusions of other mapping units are also shown on these figures, particularly in Quadrats 2 and 3. Figures 14 and 15 attempt to show the complexity of the pattern of sub-recent and recent soils on the Mowbray fan. Traverses 1, 3 and 5, illustrated on the sheet in the back pocket, also indicate the complexity of the soil pattern on the fans and hillsides. In the case of the somewhat less intensively detailed examinations, the aim is to show the extent of inclusions of other units with what may be shown on the Soil Map as an apparently homogeneous unit, and the need for the use of soil complexes, even in detailed surveys.

The problem also arises of how realistic is this limitation of less than 15% inclusion within a homogeneous soil unit before it is designated as a heterogeneous unit (USDA 1951, p. 277; Taylor and Pohlen 1962 p. 136).

It is not the aim of this study to discuss this problem in detail nor to propose solutions to it. Rather, it is merely to show that variations do occur within each soil type as mapped and that even quite large percentages of similar soils are included within the bounds of many of the "homogeneous" soil units as mapped. It is perhaps only pertinent to indicate a number of points which have emerged from the present study and which may serve as guidelines for future investigations. These are:

(a) The pattern of taxonomic units of well drained recent soils on fans is a relatively logical sequence which can be correlated with sedimentation and topography; where a fine pattern of taxonomic units are encountered the whole may be expressed as soil associations.

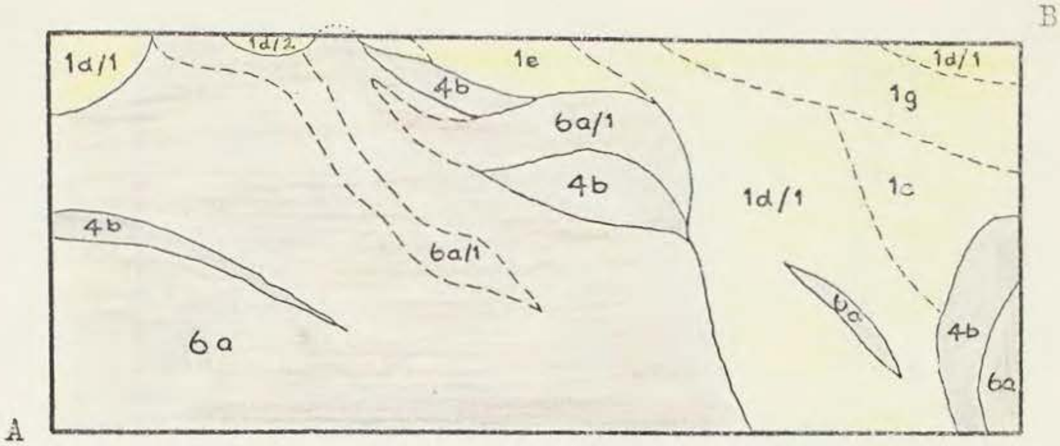
(b) In low lying areas, the complexity of the soil pattern, even following detailed mapping, is intense and not easily deducable because of slight variations in topography and the vagaries of the water table, complicated by a history of variable textured sedimentation; the taxonomic units identified under such conditions can best be expressed as soil complexes.

(c) The effects of erosion, accumulation and perched water tables on the older fan surfaces now hides relief variation which could have once been used to assist in the location of minor soil units.

(d) On the rolling and moderately steep hillsides, the differential accumulation of loess coupled with differing rates of stripping,

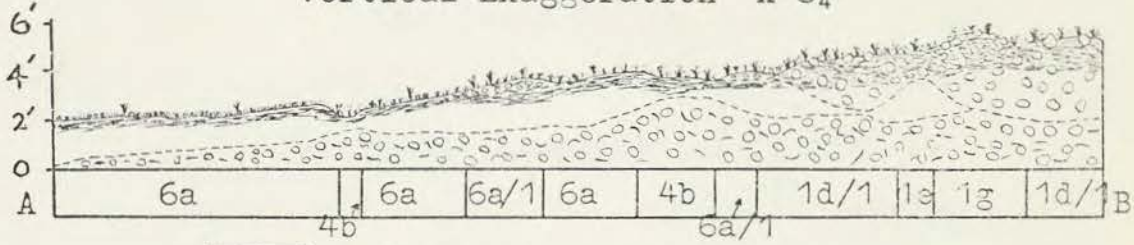
Figure 11

QUADRAT No 1



One Chain to One Inch

Vertical Exaggeration X $8\frac{1}{4}$

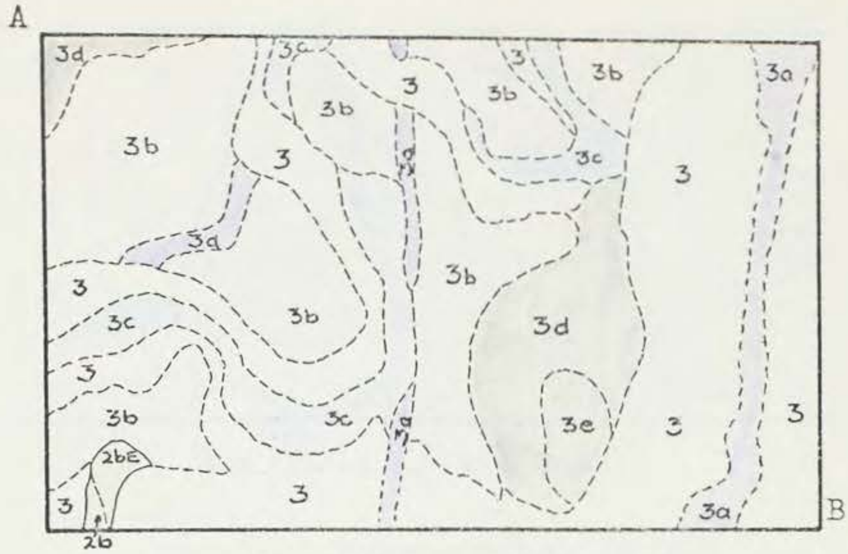


	Limit of organic enrichment
	Recent, predominantly sandy alluvium
	Predominantly gravel-sized alluvium
	Semi-recent alluvium
	Sub-recent or older alluvium
	Tussock
	Mouse ear, browntop & sweet vernal

1d/1	Tasman sandy silt loam -weak structure
1d/2	Tasman sandy silt loam -moderate structure
1e	Tasman sandy loam
1g	Tasman very stony sandy loam
4b	Ashwick fine sandy silt loam
6a	Meikleburn silt loam
6a/1	Meikleburn silt loam-stony topsoil phase

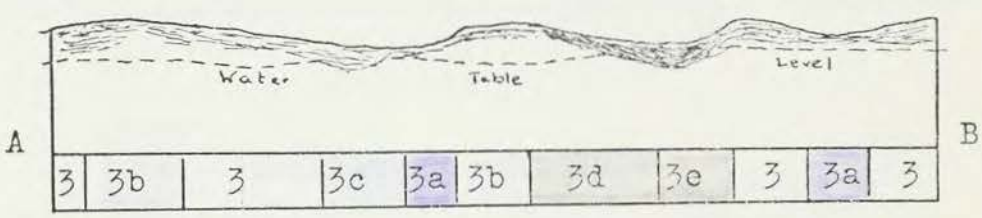
Figure 12

QUADRAT No 2



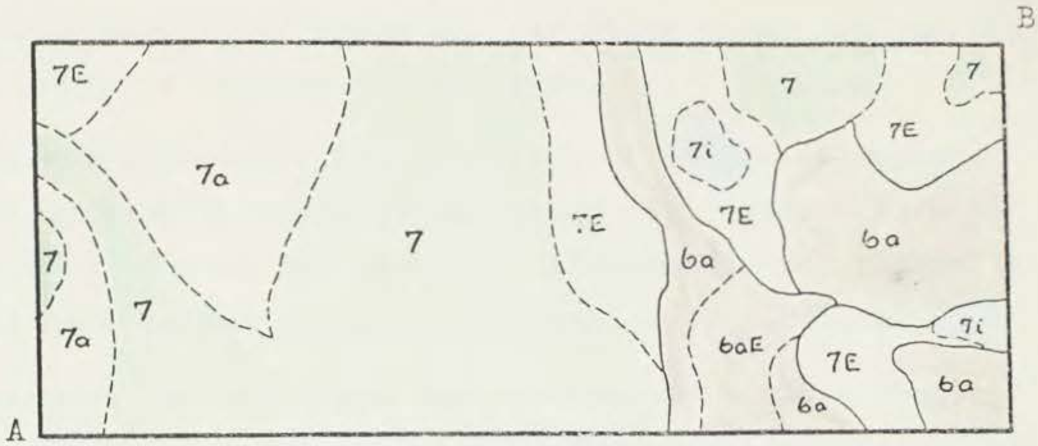
One Chain to One Inch

Vertical Exaggeration X $16\frac{1}{2}$.



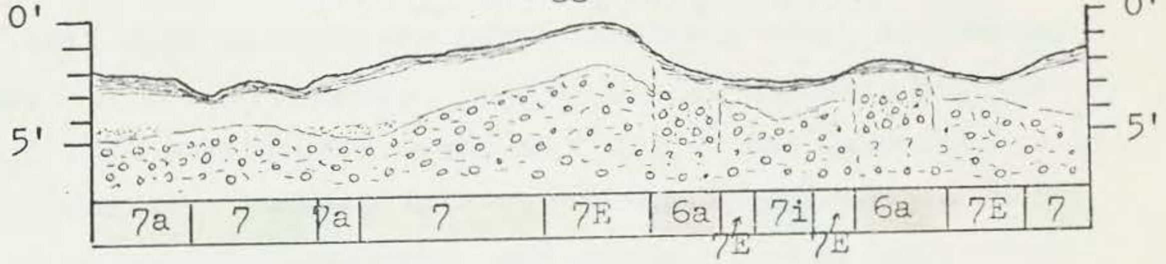
2b	Wakanui fine sandy silt loam
2b/E	Wakanui fine sandy silt loam -eroded phase
3	Taitapu silt loam
3a	Taitapu silt loam - thin topsoil phase
3b	Taitapu silt loam - eroded phase
3c	Taitapu silt loam - very wet phase
3d	Taitapu silt loam - shallow muck phase
3e	Taitapu silt loam - deep muck phase

QUADRAT No 3



One Chain to One Inch

Vertical Exaggeration X $16\frac{1}{2}$



6a	Meikleburn silt loam
6aE	Meikleburn silt loam-eroded phase
7	Sherwood silt loam
7a	Sherwood silt loam-pale olive subsoil phase
7E	Sherwood silt loam-slightly eroded phase
7i	Sherwood silt loam-imperfectly drained phase

complicated by aspect and exposure, can cause marked or, on the other hand, obscure changes in soil type.

(e) On the steeper slopes the processes of the drift regime, complicated by aspect, exposure and human interference have not been sufficient to even out previous differences, but rather in many places have tended to confound established patterns.

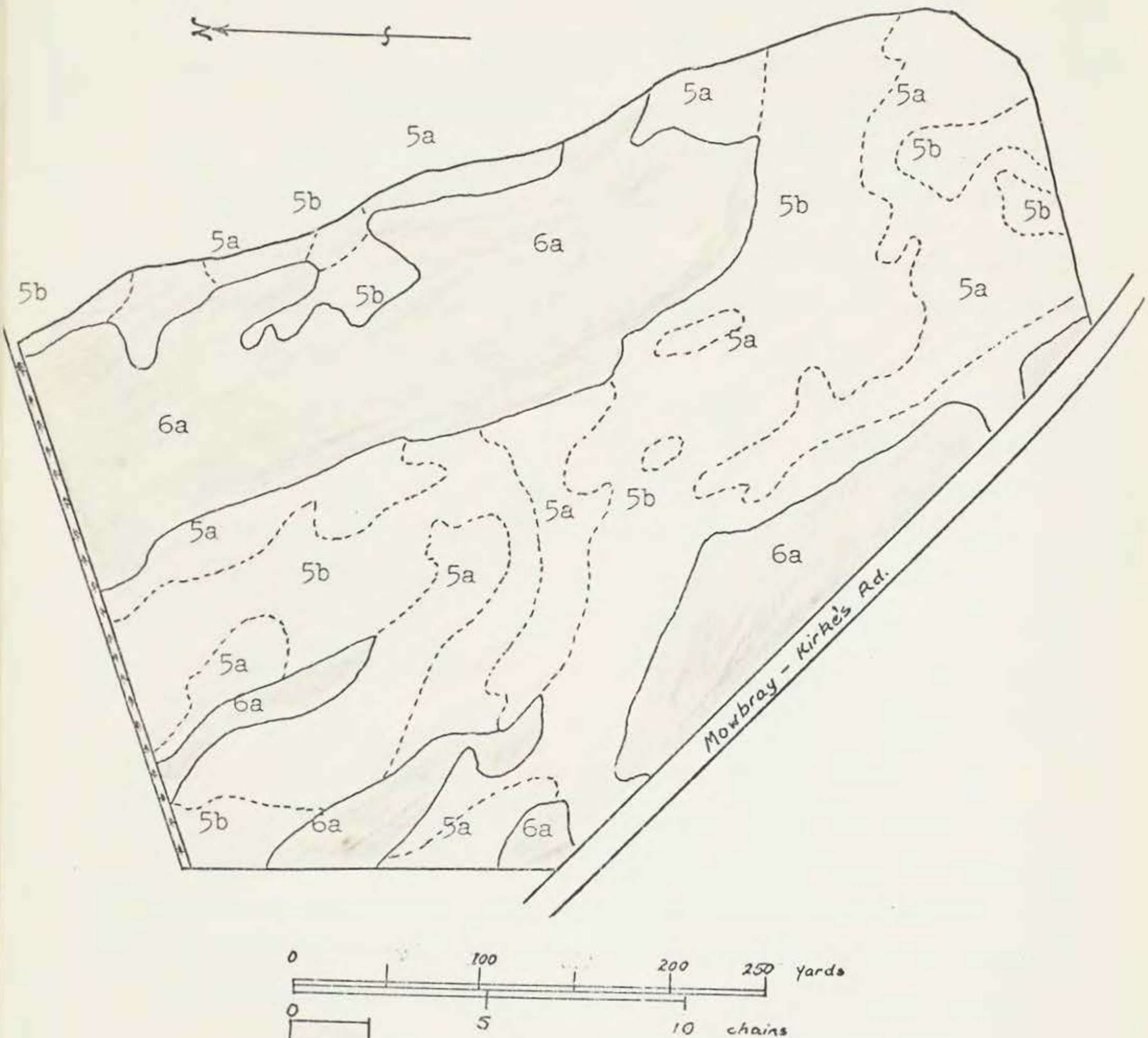
(f) In the past the soil type has encompassed a wider range of morphological and site characteristics than considered acceptable in the definition of the soil type (Taylor and Pohlen 1962). In the future, attempts should be made to have the soil type as a mapping unit conform with the basic taxonomic unit, as outlined by Taylor and Pohlen (1962). If this cannot be achieved, then each soil type must be discussed in terms of the taxonomic units which it contains. During this survey attempts have been made, as far as practically possible, and subject to the limitations discussed elsewhere, to keep within the definition proposed by Taylor and Pohlen (1962).

(g) Even at the detailed level, mapping upland and high country soils presents problems when identifying and delimiting soil types because of the number of inclusions of similar soils which must be accepted within each map unit if the final map is to remain interpretable and relatively uncluttered with symbols and lines, and, as a consequence, it may be necessary when mapping such soils to either:

i. redefine the concept of the soil type as a mapping unit, or
ii. use coarser units of mapping for such surveys, even on detailed maps.

DETAILED SOIL MAP OF THE BARLEY PADDOCK

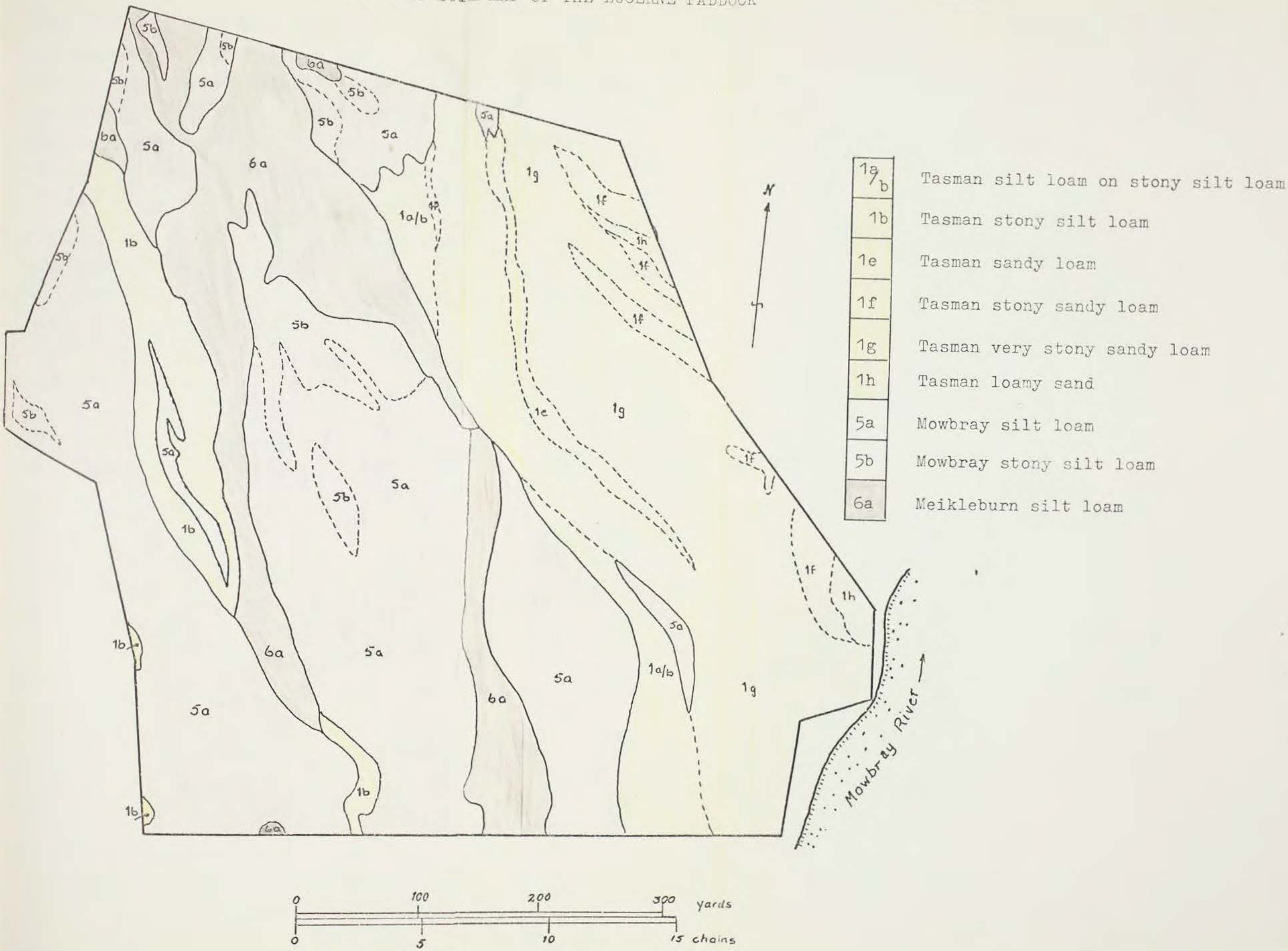
Figure 14

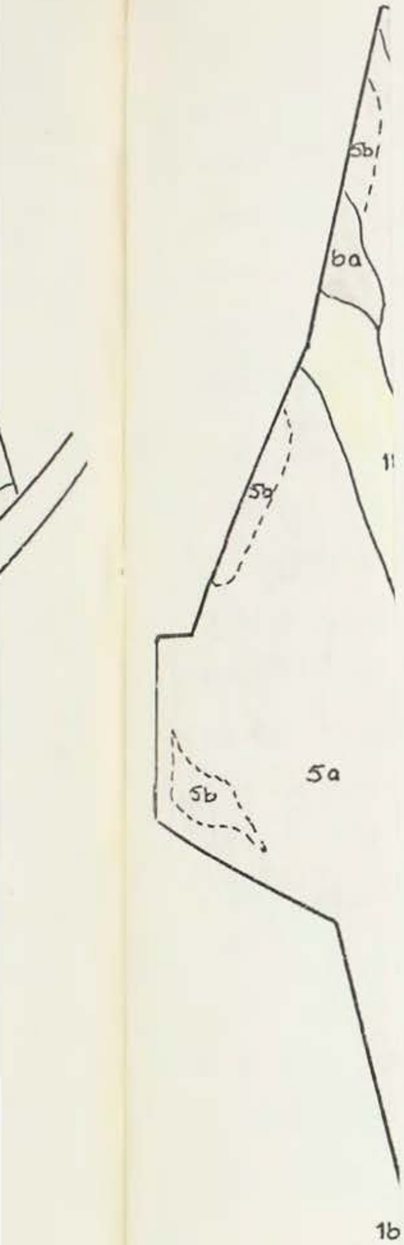


5a	Mowbray silt loam
5b	Mowbray stony silt loam
6a	Meikleburn silt loam

Figure 15

DETAILED SOIL MAP OF THE LUCERNE PADDOCK




5b
6a
1
5a
5a
5b
1b

(h) Thus, in relation to (g) and (i), in many cases where soils are derived from moderately deep accumulations of loess, the soil on hilly land is similar to that on rolling land. Consequently proliferation of phases within a type can be avoided on detailed maps by a simple redefinition of the environmental range. The use of an elementary cartographic device would then be all that was necessary to show terrain differences within the type.

(i) Physical and logistic problems impose definite limitations on the degree of intensity of detailed survey on steeplands. It is debatable whether delimitation of types is of practical use on steep slopes. Certainly its usefulness is questionable in areas similar to the upper basin of the Mowbray catchment. Soil sets, which on steeplands are complexes of types of a series with inclusions of types from related series, are not sufficiently discriminate to show differences of significance for land use. Consequently, a taxonomic unit intermediate between set and type would be the ideal. The soil series, as a txonomic and mapping unit would fill this requirement. The range of types within each series should be determined and their characteristics described. Selected detailed traverses is the best method of illustrating the range within series on such terrain.

CHAPTER VIII

SOIL GENESIS

In a comprehensive study of this kind it is difficult to know where to start when discussing the influences of the factors (Jenny 1941) and processes (Taylor and Cox 1956) of soil formation on the development of a range of soils such as those encountered in the Mowbray area. Each of the factors of soil formation may be discussed with reference to the soils, but the notes on the environment (Chapter IV) have probably more than adequately covered this approach. The relationships and influences of the soil forming processes then may serve as the best approach at this stage. Again difficulty is encountered in deciding whether it is better to discuss the soils in terms of the genetic groupings or in terms of their physiographic arrangement. Since the former arrangement presupposes prior assessment of many factors of soil genesis it has been decided to maintain continuity with the arrangement of soils in Chapter V and discuss the formation of the soils according to the physiographic groups.

1. SOILS OF THE FLOODPLAINS, TERRACES AND YOUNGER FANS

(1) Well Drained Soils

(a) Inferences from Site Factors, Morphology and History

The well drained soils from alluvium on the Orari, Meikleburn and Mowbray fans and on the terraces of the Mowbray show a distinct age-developmental sequence. This sequence is demonstrated in the degree and depth of profile development of the soils on these surfaces. Tasman series have A / AC / C profiles. Ashwick and Mowbray series have respectively A / AB / BC and A / AB / (B) / BC profiles. The Meikleburn soils, which are considered to be significantly older, average 19" of solum and have A / AB / B / C profiles. The relationship between these soils is presented graphically in Figure 16.

The soils have been formed from the weathering of a series of depositions of greywacke alluvium. Meikleburn gravels were laid over older alluvium possibly deposited during an interstadial period. On the upper parts of the fans the Meikleburn gravels overlie the older gravels but on the lower Meikleburn fan these later deposits were left in channels cut into the older alluvium (see Fig. 13). Subsequent depositions of gravel have formed the parent materials of the Mowbray and Ashwick soils.

The Meikleburn soils have probably been exposed to the influences of weathering and leaching over the last 10,000-14,000 years, under a climatic regime roughly similar to that existing today, and probably under both forest and grassland associations. Some erosion may have modified the rate of soil formation and it is not improbable that the counter process of accumulation may have also occurred (Plate 19). The Mowbray and Ashwick series are developed over deposits of younger age. Soil formation has not proceeded to the same extent as within the Meikleburn series but as with this latter series, the opposing processes of accumulation and removal have probably been differentially operative at various times. Although shallow and stony, these soils have probably supported both forest and grassland associations since their inception (Vucetich 1968).

These three soils occur in a climatic zone which has been typified as characteristic of that inducing yellow-grey earth formation (Hurst 1951 and Climate in Chapter IV) with a sub-hygrous moisture regime. The soils of this class, however, lack a pan (although [illegible] a fossil pan may be present in the

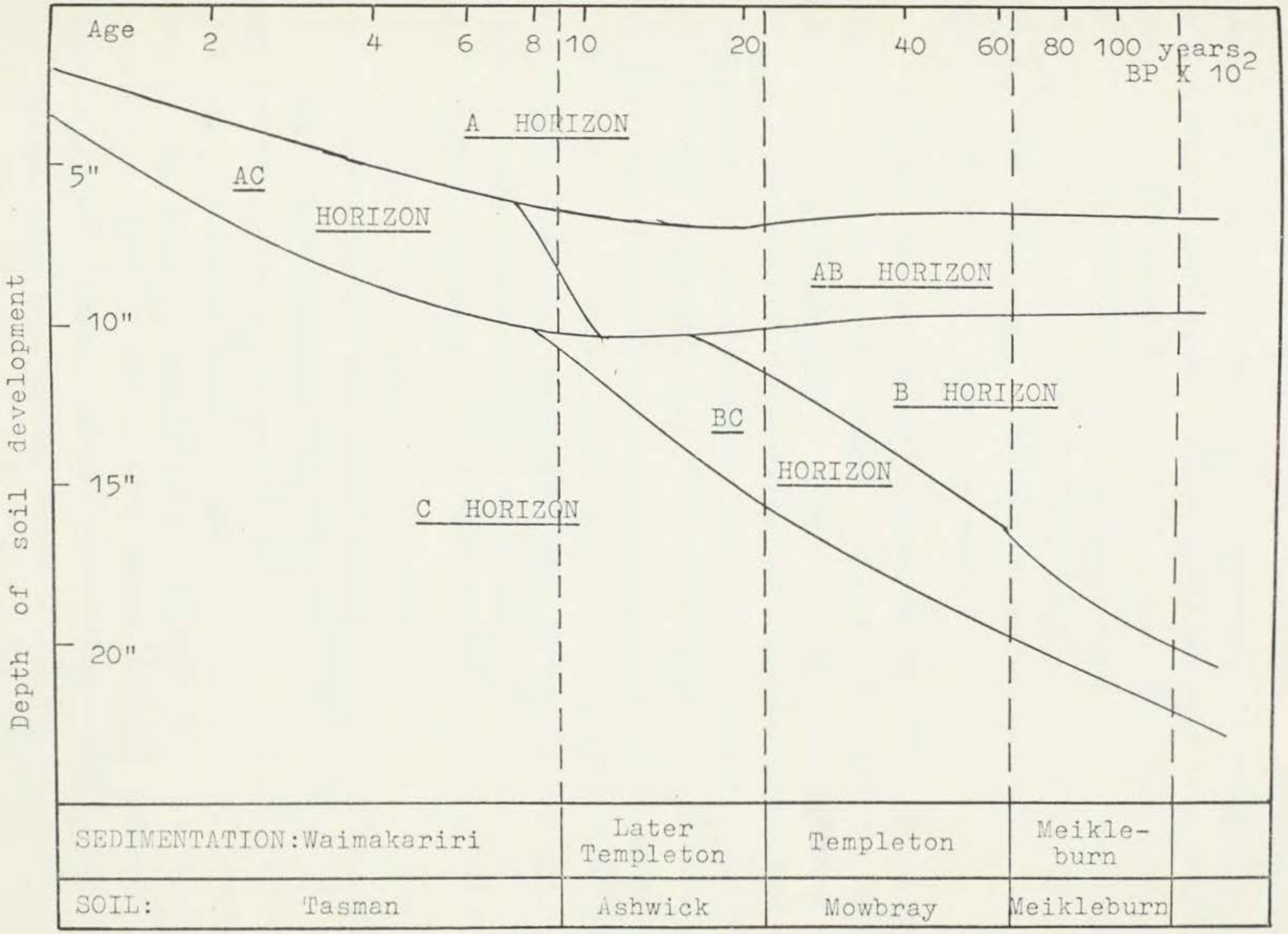


Figure 16 SCHEMATIC DEVELOPMENT OF SOILS ON TERRACES AND YOUNGER FANS

underlying alluvium), have friable consistence and weak nutty, rather than moderate nutty or blocky structure, in the B or BC horizons - all features of yellow brown earths. In addition, subordinate crumb structure is a characteristic of the A horizons, particularly of the Ashwick and Mowbray series. On a morphological basis then, the three series of this class could be better grouped with the yellow brown earths. However, to maintain conformity with the classification used during the South Island survey (Soil Bureau Staff 1968a) they have been classified as yellow grey earths to yellow brown earths intergrade.

Of much younger age and minimal profile development are the Tasman series. They are formed over deposits of recent alluvium probably laid down during the last 900 years. The effects of the organic cycle are visible in these soils but there is little other morphological differentiation. Differences in phosphate levels (see Table 9) between younger and older soils of this series indicate that the early stage of weathering has commenced (Syers et al 1969) and plant nutrients are being removed by leaching. Because of a discontinuous grass cover which developed on the stony and very stony Tasman soils, considerable loss of fine material may have occurred since the deposition of the parent gravels.

(b) Major Influences in Soil Formation - The principal factors affecting the formation of the soils of the terraces and younger fans have been the texture of the alluvium and the time the soil forming processes have had to act on the parent material. The actual degree to which the texture of the parent material has affected weathering in relation to the moisture regime is somewhat obscure, but it is probable that in such areas of relatively low rainfall, coarser textured alluvium weathers at a more uniform rate to a greater depth than finer textured alluvium.

This is due to a smaller total specific surface than is presented by the finer textured alluvium and resultant soils, and consequently a given amount of moisture is distributed more evenly and to a greater depth than in finer textured soils. As a result weathering is effective to a greater depth in coarser deposits but is not necessarily more rapid than that occurring in finer textured materials, which will obviously show more pronounced effects of wetting and drying cycles. In addition through-percolation is more rapid in coarser textured alluvium thus effecting a greater rate of translocation of the products of weathering.

Stony and very stony soils have redder hues, and higher chromas and values than non-stony soils of equivalent age. The very friable and porous nature of the stony and very stony soils allows extensive root ramification to a greater depth and a greater depth penetration of organic matter than in soils of finer texture. Pan formation does not appear to be a process currently occurring within the solum but thin weakly formed iron pans have been observed in the underlying gravels. Panning at these depths is characterised by very dark red coatings on the under-surfaces of stones and may result from present lateral flushing of iron enriched ground water or may be a relict feature from an earlier depositional phase.

Wind erosion has been particularly active on these surfaces especially at times when vegetation was sparse. Deflation of low rises has brought about a concentration of coarser components in the upper part of the horizons. In addition washings of fines, following heavy rain, from the low rises into adjacent hollows has led to a thickening of the upper horizon in these hollows. In these sites, soils have better moisture retention than those on low rises and consequently have tended to be better vegetated.

This additional factor, coupled with the more rapid drying out of the more exposed low rises, has aided wind in its deflation of these sites.

(2) Imperfectly and Poorly Drained Soils

(a) Inferences from morphology, site factors and history - The pale coloured subsoils and prominent mottling seen in these soils in indicative of a past history of poor drainage conditions. Their morphology suggests periodic accumulation of fine sediments but a detailed examination of their texture profiles would be necessary to substantiate this. They occur on flat to depressional areas adjacent to small streams and have deeper A horizons with higher levels of organic matter than the adjacent well drained soils. In places the A horizon of the Taitapu series has a muck-like (Leamy and Panton 1966 p. 69) character and at one site about three feet of dry peat was observed under a red tussock.

Because of the masking effect of high water tables on horizon development and identification, it is difficult to determine the actual depth of soil developed in the present cycle. It appears, however, that the Wakanui soils have about 12" to 14" of solum, which incorporates the whole of recently deposited material, while the Taitapu soils show only 8" to 12" of soil development, the lower parts of recent sedimentation retaining its original character. It is because of this deeper development of solum, better profile differentiation and structural development, and their occurrences on slightly higher surfaces, that the Wakanui series are considered to be older than the Taitapu series.

The washing of fine alluvium from the Meikleburn surface onto early Meikleburn or older gravels probably gave rise to the Wakanui soils in later Meikleburn times. The alluvium was deposited over the floodplains of streams adjacent to the fan margins. Subsequent erosion resulted in the accumulation of fine material from this and adjacent surfaces in low lying areas of high water table. It is considered that, because of the fine texture of the alluvium deposited at this later stage, the site of deposition was a very wet swampy area which may have existed periodically as a shallow lake. The apparent lack of buried, highly organic deposits or buried timber tends to support this theory. The cutting of a channel by the Meikleburn stream, through the region of coalescence of the Mowbray and Orari fans in later Templeton or early Waimakariri times, resulted in the drainage of the lake and led subsequently to the formation of the Taitapu series.

(b) Major influences in soil formation - The principal factor affecting the formation of these soils is that of topography as manifested in the varying height of the water table. The poor drainage periodically experienced by the Wakanui soils led to the acquisition of incipient gley features in the form of pale coloured subsoils. Reduction in the level of the water table has produced the distinct mottling, following oxidation of mobilised iron compounds, and has led to the acquisition of weak morphological features analagous with those of the yellow-grey earths.

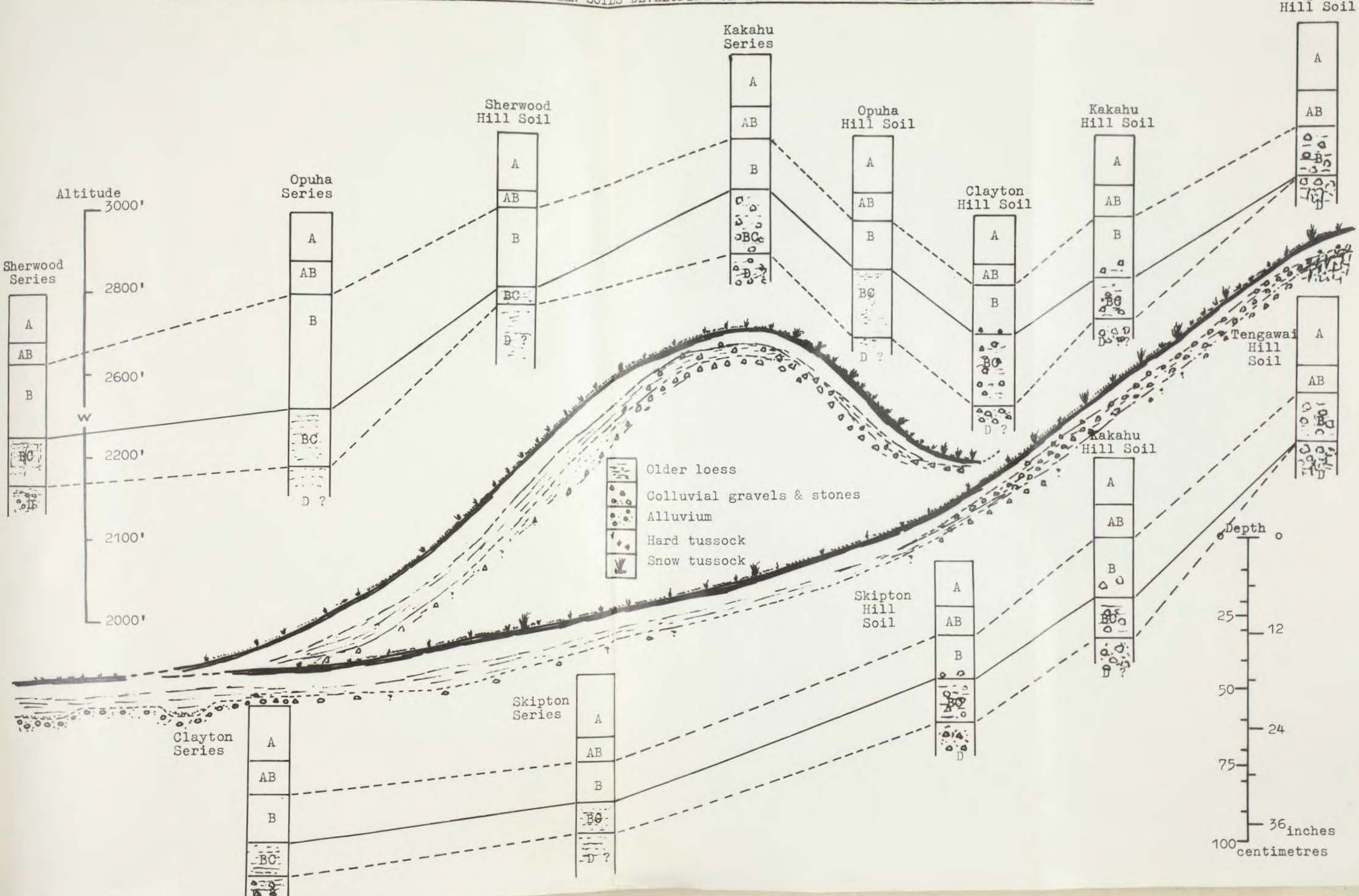
Recent exposure to aerobic processes of the waterlogged areas of fine alluvial accumulation has given rise to the Taitapu series. Drainage in recent times has had little effect on the hydromorphic features inherited from the time when the water table was permanently at or above the surface. Only the processes of the organic regime have been sufficiently active to introduce pedological contrasts in these soils.

2. SOILS OF THE OLDER FANS AND ROLLING HILLSIDES (including related hill soils)

(a) Inferences from morphology and site factors - Soils included within this class are those yellow grey earths and

FIGURE 17

SCHEMATIC DIAGRAM SHOWING THE RELATIONSHIP BETWEEN SOILS DEVELOPING ON ROLLING AND HILLY HILLSIDES AND OLDER FANS



yellow-grey to yellow-brown earth intergrades which are derived from loess lying on an older loess layer or over an accumulation of mixed loess and colluvial materials. The discussion includes the Tengawai hill soils since it is considered that many of these soils fall into the latter category.

These soils are so grouped because it is believed that they are all developing to a large extent from accumulation of loessial material, either by windborne accretion or by gravity from upslope, largely deposited in early post glacial times. Such loess overlies an older loess or mixed loess/colluvial material accumulation which was probably part of a former deposit accrued during the last stadial of the Otiran glaciation. The younger loess appears in the position of a solum of these soils. The BC and so called C horizons (although more correctly designated as D horizons - Taylor and Pohlen 1962 p. 72) represent the weathered or weathering upper part of the older loess and mixed loess and colluvium deposits. Evidence will be presented later to support this conjecture.

It has not been possible to fit these soils into a definite sequence, although they are arranged in an idealised topographic sequence in Figure 17 in order to show their inter-relationships. These soils represent a series of sequences, which may comprise as few as two members. The difficulty of determining true sequences wherein differences in morphology may be attributed to the variation of a single factor or a combination of factors has been outlined by Gregg (1969) and was dramatically encountered by Witchalls (1969) when he investigated a chemical and mineralogical sequence of yellow-brown earths in Otago and Southland.

However, in order to show similarities and differences

SCHEMATIC PRESENTATION SHOWING THE DIFFERENTIATING FEATURES OF THE POLYSEQUENCE OF SOILS DERIVED FROM RECENT LOESS.

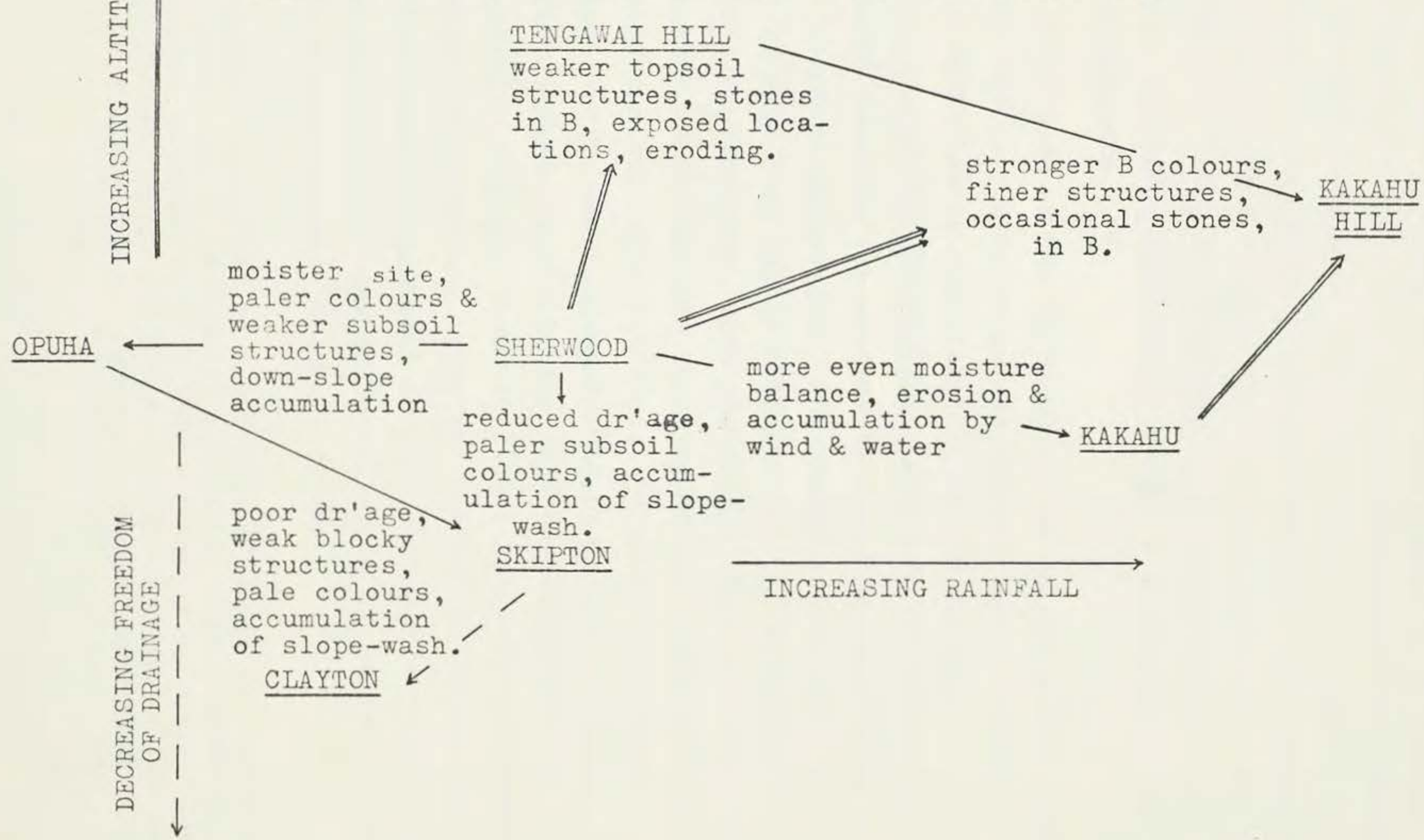


Figure 18

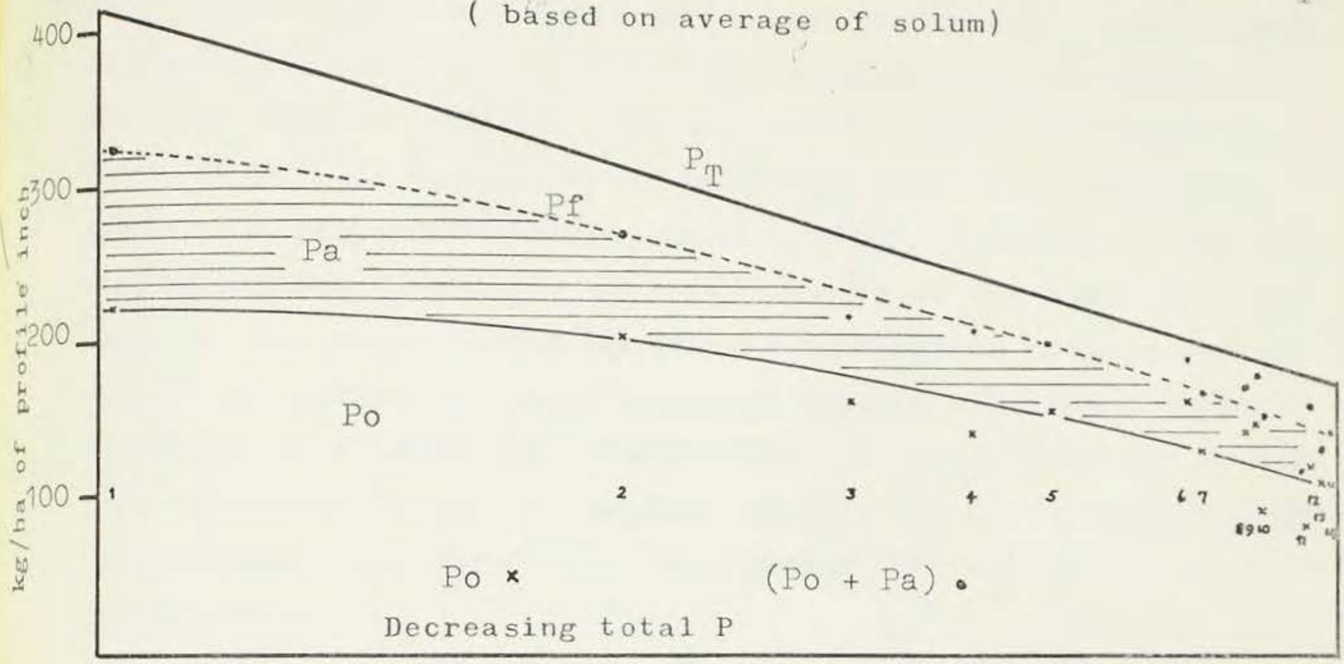
between these soils they may be considered as a loose grouping herein called a polysequence*. The Sherwood series is considered to be the central concept of the polysequence of soils on loess. Figure 18 shows a diagrammatic representation of the morphological, and site features which differentiate the related soils from the central concept. Table 15 shows the broad morphological and developmental relationships between these soils and those on hilly and steeplands.

The occurrence of the Sherwood series on old gently sloping fan surfaces and on convex hillsides showing similar stages of development testifies to the stability of the Sherwood hill soils. In their relatively dry environment the weathering and leaching of fresh material reaching the surface is probably balanced by the removal of material by erosion. The apparent advanced stage of weathering is more than likely attributable to the pre-weathered nature of the acquired clay size particles. The dry conditions probably retard weathering and leaching of nutrients released from the sand and silt size fraction. Tengawai hill soils experiencing similar environmental conditions and in continuity of "Pedomorphic surfaces" are slightly less developed than the Sherwood series. They are found at higher altitudes and experience greater extremes of weather. They are subject to erosion and as a consequence there is a renewal of the solum due to weathering into the underlying loess and colluvial material, probably coupled with mixing associated with downhill creep.

* A polysequence is defined as a grouping of soils on similar parent material, and it is broadly similar to a soil suite; it differs in that it contains more than one sub-suite which varies from a central concept in the effects of the impress of different dominant soil forming factors and soil forming processes.

(a) Changes in form of phosphorus in soils of the Mowbray Catchment arranged in order of decreasing total P (P_T)

(based on average of solum)



1 Tekoa (MC.77)
2 Tengawai (MC.85)
3 Kaikoura (MC.70)
4 Sherwood (MC.53)
5 Lookout (MC.64)
6 Tengawai hill (MC.44)
7 Tengawai hill (MC.72)
8 Opuha hill (MC.79)
9 Kakahu (MC.28)
10 Kakahu hill (MC.81)
11 Kaikoura hill (MC.83)
12 Skipton (MC.89)
13 Puketeraki (MC.69)
14 Puketeraki hill (MC.84)

(b) Idealised curves showing changes in form of phosphorus during pedogenesis. (after Walker 1965)

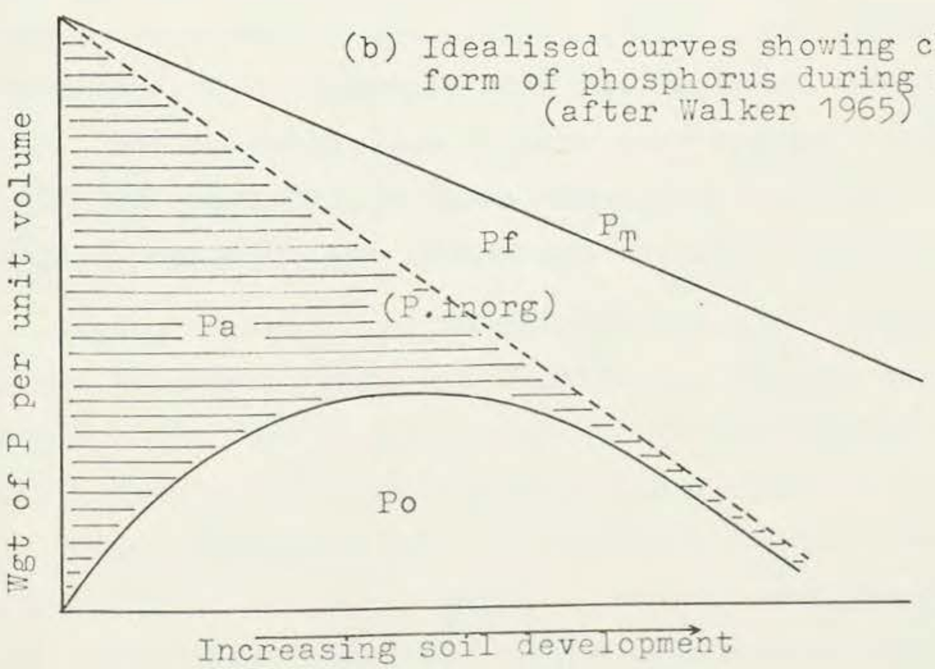


FIGURE 19 CHANGES IN FORM OF PHOSPHORUS DURING PEDOGENESIS

Opuha series are found in less exposed sites, have deeper accumulations of wash and windblown materials and are moister than the Sherwood series. The impeded drainage experienced by these soils, due to the poorly permeable nature of the parent loess, has prevented complete oxidation of the released iron compounds and has given rise to paler colours in the subsoil of this series. Generally cooler and moister conditions have tended to reduce the effectiveness of seasonal wetting and drying cycles, which are to a large part responsible for the development of subsoil structure in the yellow-grey earths. As a consequence Opuha series shows less structural development than other members of the polysequence.

Also in moister sites are the Skipton series which are, however, due to their greater exposure than the Opuha series, as equally developed as the Sherwood series. In poorly drained locations the Clayton series may be separated from these series. Coarser structures, pale matrix colours and strong mottling testify to the influence of topography on the moisture regime and hence on the development of the Clayton soils which appear to be of a lesser stage of development than the Sherwood, Opuha and Skipton series. The Sherwood $\longrightarrow$ Skipton $\longrightarrow$ Clayton series represent a hydro-topo-sequence in which the arrows indicate decreasing freedom of drainage and increasing receipt of runoff.

Kakahu series occur in moister but more freely drained sites than the Sherwood, Opuha and Skipton and Clayton series. The very fine nutty and crumb-like A horizon structures in the Kakahu series are indicative of a more active biological regime than in those series mentioned above. B horizon colours tend to be redder, particularly in the soils on hilly terrain and the friable nature of the lower solum indicates a more even dispersion of free iron than in those series mentioned above. The Kakahu soils on hilly

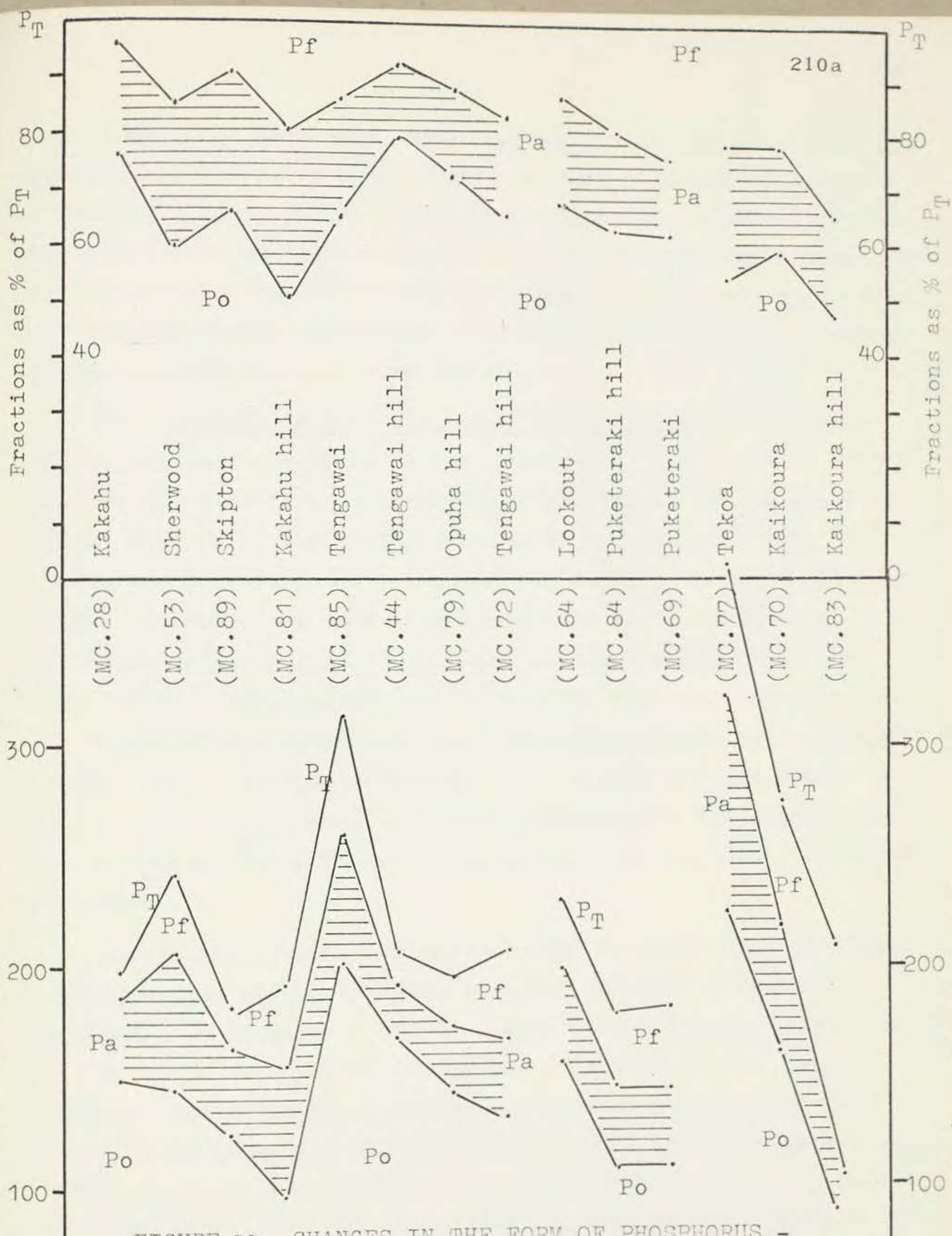


FIGURE 20 CHANGES IN THE FORM OF PHOSPHORUS - SOILS ARRANGED ACCORDING TO PARENT MATERIAL IN DECREASING AMOUNT OF Pa as %age of P_T

(fractions as % of P_T above; and as weight / unit vol.)

terrain are more developed than the Sherwood series but on undulating and rolling terrain this series, although at the same stage of development as the Sherwood series, is moderated in its character by the mixing of recently accumulated material throughout the solum. Solifluction (Plate 21) is also a feature of the hill soils of the Kakahu series and is responsible for bringing underlying colluvial material into the solum.

(b) Inferences from chemistry and mineralogy - Before entering a long discussion on the possible significance of the chemical and mineralogical analytical results it is important to realise that while the profiles selected for analysis were considered to be typical of the series, it is quite possible that the results obtained, represent the extreme of the series, since in most cases only one profile for each series or hill phase was investigated. (Not forgetting, of course, that the results for each series do correlate with the chemical variability acceptable for that series on a national basis). Consequently statements based on these analyses are somewhat conjectural and a more extensive investigation would be needed to confirm or reject the ideas propounded.

Mineralogical and chemical data on the soils sampled appear in the appendix and in addition selected data are presented graphically in Figures 21 and 22. Figure 19 attempts to show how the changes in form of the phosphorus fractions in the soils relate to soil development based on the idealised successional changes first suggested for New Zealand soils by Walker and Adams (1959). Based on the assumption that decreasing amount of total phosphorus correlates with increasing weathering and leaching it can be seen that the sequence of development is: Sherwood series are apparently less developed than Tengawai hill soils which in turn are less developed than the Opuha, Kakahu and Skipton soils in that order. However, in view of the variations in P content of the parent materials (see Table 15) arranging the soils in order of decreasing Pa as a percentage of the total inorganic P (Pinorg) was considered to give a better indication of a developmental sequence (Witchalls 1969). This is because such a ratio operates irrespective of the total amount of inorganic P present and is dependent on development. Since, as weathering and leaching proceed Pa is eventually converted into Pf (Walker 1965); Figure 20 shows such an arrangement. However, such a sequence does not conform with that revealed by morphological assessment but variation in absolute amount of the different P fractions could contribute to the poor correlation (Figure 20). A sequence based on Pf as an increasing % of Pinorg, however, has better conformity with the morphological trends than that arrangement based on decreasing total P (Figure 19a).

Table 15 - Variations in Total P Content of C and D Horizons

	Profile no.	P_T p.p.m.
Loess (pre-weathered	53	334
	79	215
	89	325
Weathered Greywacke	44	1144
Weathered Argillite	77	925
Unweathered Greywacke	-	1100

When the fractions are expressed as a percentage of total P a rough sequence emerges. The variations which occur between soils is almost certainly due to the differences in absolute amounts of each fraction; a direct result of the influences of the various environmental factors on the members of the polysequence. An

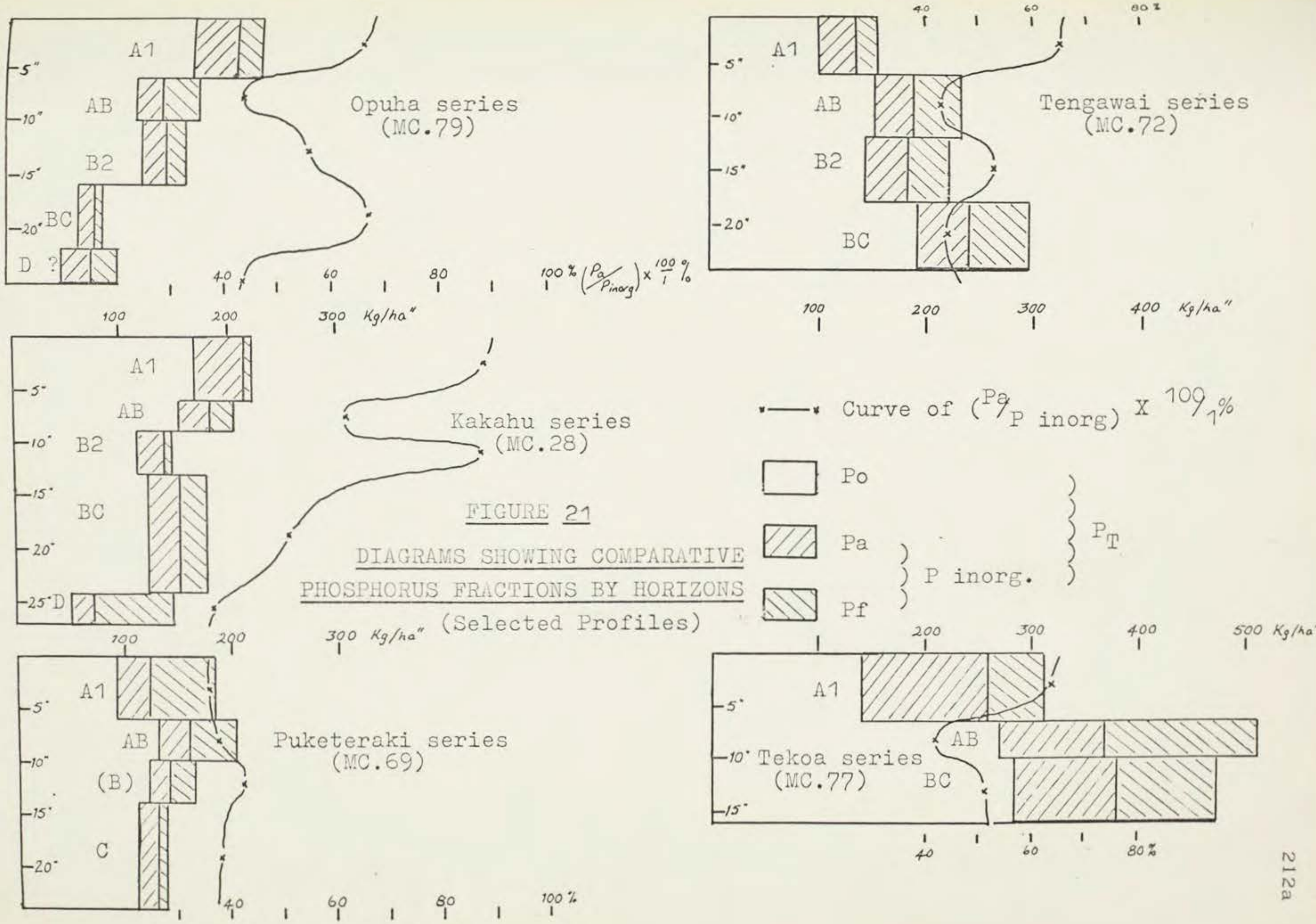
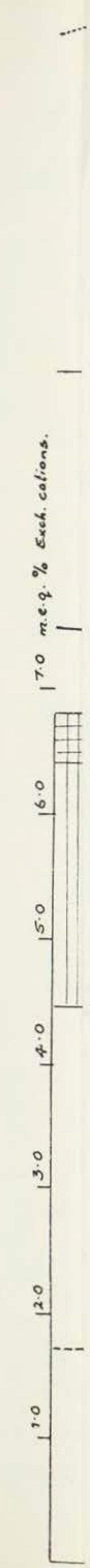


FIGURE 21

DIAGRAMS SHOWING COMPARATIVE
PHOSPHORUS FRACTIONS BY HORIZONS
(Selected Profiles)



1.0
2.0
3.0
4.0
5.0
6.0
7.0 m.e.q. % Exch. cations.

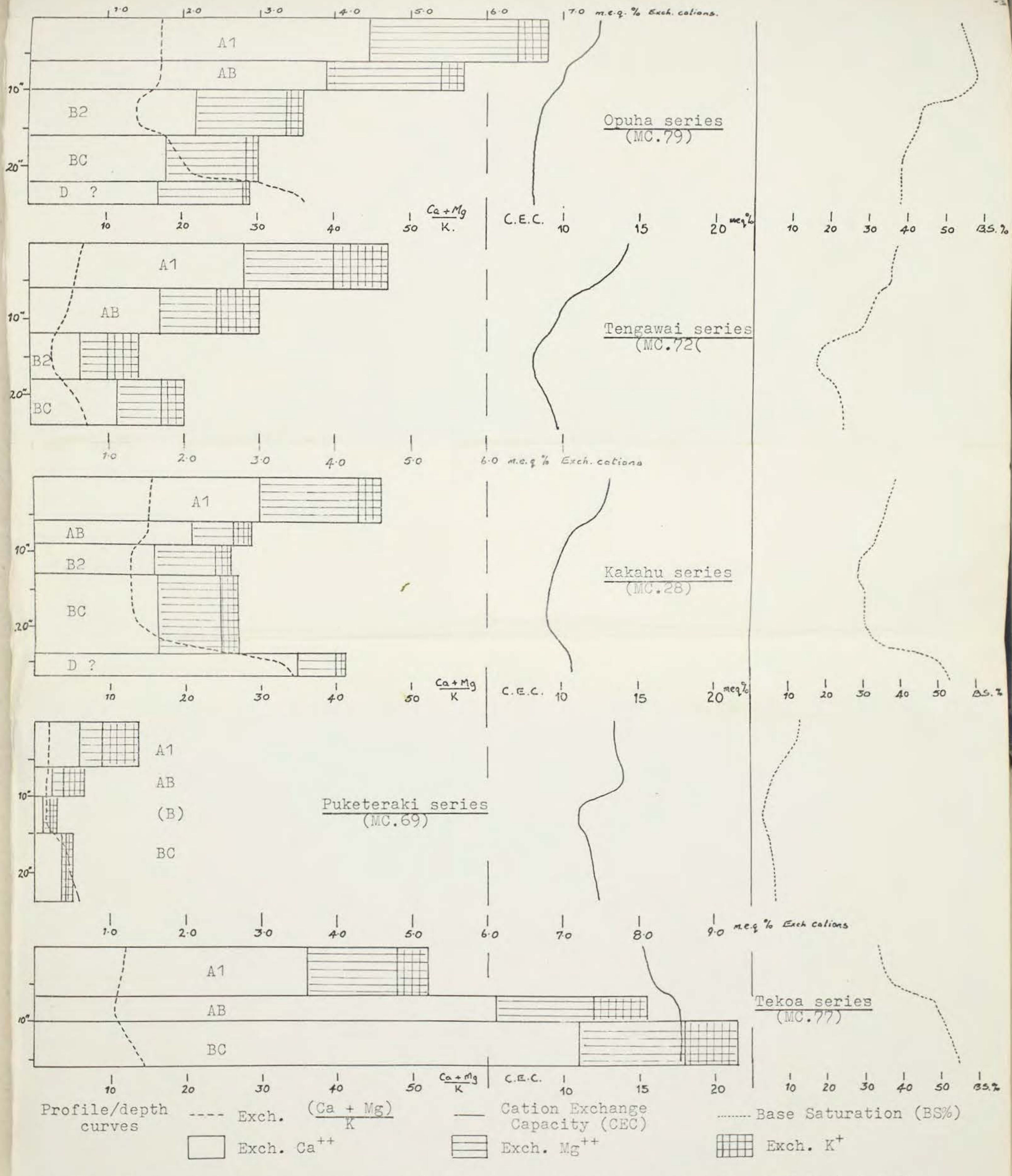


FIGURE 22 Comparative Diagrams Showing Features of the Exchange Complex of Selected Soils

arrangement on the basis of increasing Pf as a percentage of total P gives a picture of development which is closer to that shown by morphology - Pf/P_T decreases as BS% increases. The corresponding Pa/P_T and Po/P_T relationships, however, do not correlate well with the idealised changes suggested by Walker (1965) shown in Figure 19b (see also Figures 21 and 22).

The BS% (base saturation) and the levels of exchangeable bases indicate stages of development roughly similar to those suggested by the morphology and site factors (Figure 22). However, the apparent advanced stages of leaching indicated by these low base levels is not in keeping with that considered normal for these soils (Soil Bureau Staff 1968a) and consequently it is most probable that the base status of the loessial material was low at the time of deposition.

It is also probable that the loess contained clay minerals indicating early or medium stages of weathering, according to Fieldes and Taylor (1961) or Jackson (1964). Thus it is difficult to draw any firm conclusions relating to weathering based on clay mineral assemblages until one is able to determine the actual composition of the original parent material at the time of deposition. If the underlying loessial material is considered to be the parent material then in most cases it would appear that reversal of the weathering stages of Fieldes (Soil Bureau Staff 1968b p. 26) has occurred, since the clay mineral assemblages of the underlying loess indicates a more advanced stage of weathering than that of the solum above. Figure 23 attempts to illustrate this point for selected profiles. In the soils derived from loess, micaceous 10 Å material increases down the solum but then decreases rapidly in the underlying C/D (?) horizon. In a reverse fashion, clay-vermiculites decrease down the solum and increase rapidly in the underlying material.

However, despite these limitations it is possible project a weathering-developmental succession based on mineral transformations in line with those proposed by Fieldes (Soil Bureau Staff 1968b). Reduction in amount of micaceous material and an increase in the amount of clay vermiculite are taken to indicate an increase in soil development. On this basis the Opuha and Kakahu series are less weathered than the Tengawai hill soils which in turn are less weathered than the Skipton and Sherwood series, with the Kakahu hill soil indicating the maximum amount of weathering, found in this polysequence.

It does appear that the soils of this polysequence which have the higher pHs and higher levels of exchangeable Ca tend to weather to form clay-vermiculite (2) rather than clay-vermiculite(1) which appears to be the dominant weathering product in the Kakahu, Tengawai, Sherwood and Kakahu hill soils. (See Appendices and Figure 22 for presentation of analytical data.) This trend corresponds to suggested development trends proposed by Fieldes (1958 and 1968), Fieldes and Swindale (1954) and Fieldes and Taylor (1961).

(c) Major influences in soil formation

A. The effect of the drift regime - The effect of the drift regime and both directly and indirectly the effect of the topographic factor are the major influences which have exerted a control over the direction and rate of soil formation amongst the soils derived from loess.

Rate of accumulation of material by wind is dependent upon:

i. provision of a source of material in the path of prevailing winds;

ii. aspect and exposure of slopes and surfaces relative to the direction of supply;

Figure 23 - Crystalline Clay Mineral/Depth Functions for selected profiles to show the more advanced stage of weathering in the underlying loess or mixed loess and colluvium than in the loess derived solum.
(Soils derived from colluvium shown for comparison)

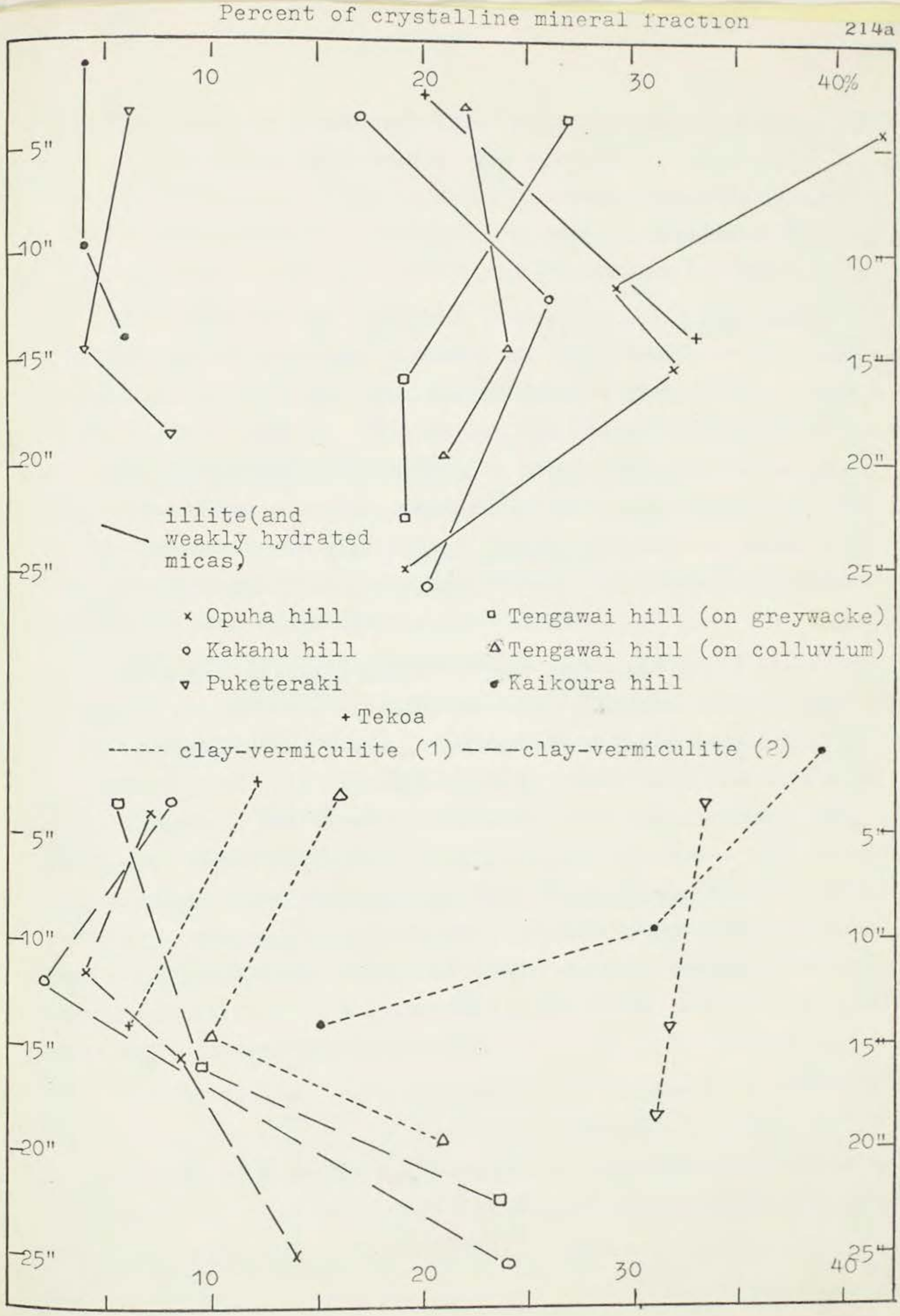

Percent of crystalline mineral fraction
10
20
30
40%
5"
10"
15"
20"
25"
inc. profile depth.
illite(and weakly hydrated micas)
× Opuha hill
○ Kakahu hill
▽ Puketeraki
□ Tengawai hill (on greywacke)
△ Tengawai hill (on colluvium)
• Kaikoura hill
+ Tekoa
------ clay-vermiculite (1) — — —clay-vermiculite (2)

FIGURE 23

iii. angle of slope and runoff characteristics of the surface; and finally the

iv. frequency, velocity and persistence of winds which must lift and transport material of various size grades varying distances and to varying heights.

Coupled with the influence exerted by the differential accumulation of windblown material are the effects of the washing of both recently accumulated and older surficial material onto soils at lower levels. In addition the introduction of both fresh material from underlying weathering stones and pre-weathered associated fines may have occurred in the lower horizons of the solum of some of the hill soils. Minor solifluction appears to have been a phenomenon occurring amongst the Kakahu and Tengawai hill soils (see Plate 21).

Thus the physical nature of the loess and wash material accumulating on these surfaces can vary considerably from site to site. Generally the coarser fraction is derived from higher elevations (i.e. the sand fraction increases with increasing slope and altitude). The finer fractions of silt and clay show only minor variations with increasing altitude and slope. The relationship between these fractions and the distribution of P fractions in the soil, however, is less clear. The following observations (based on the average levels of P fractions in current profiles) regarding the relationship between P fractions, site factors and mechanical fractions may be made:

(i) Pa as % P_T - decreases with increases in altitude, slope and % sand;

(ii) Pa as % Pinorg - decreases with increasing altitude and with increasing sand content and clay content;

(iii) P_f as % P_T - increases with an increase in all size fractions;

(iv) Pinorg as % P_T - increases with increasing silt and increasing clay content, but decreases with increasing altitude and increasing sand content;

(v) P_T - increases with increasing silt content and decreases with increasing sand content and increasing altitude.

It is apparent then that the major source of P in these soils derived from loess is associated with the silt fraction and the clay fraction. The major part of the inorganic P is most probably associated with the silt fraction. A similar conclusion to that reached by Shah et al (1968) and Syers et al (1969). Pa as a % of P_T and P inorg. is greatest in the silt fraction and it is from this fraction that the greatest loss of Pa occurs with increasing soil development (Shah et al (1968 and Syers et al (1969). The relationship between P_f as a % of P_T, and the various size fractions is more difficult to assess and it is probably most adequately explained by a compromise between:

i. a variation in the actual nature of the form(s) of P extracted by $N.H_2SO_4$ (Shah et al 1968), and

ii. the occurrence of P_f as both occluded P in the clay and fine silt fractions and as included P (apatite included within the crystals of other minerals) in the coarse silt and sand fractions.

The reduction in Pa as a % of Pinorg with increasing altitude is a result of increasing rainfall and conforms with conclusions of Ludecke (1962). Since the coarser component in these soils is considered to result from down-slope movement of material derived from the underlying greywacke it is logical to assume that a large part of the acid extractable Ca - P of the Pa (Williams 1965, Shah et al 1968, Syers et al 1969) in the form of comparatively readily soluble apatite (Williams et al 1969, Syers et al, in press) has already been removed following weathering in upslope locations. Recent work on the mineral transformations in a deeply weathered soil on greywacke (Syers et al, in press) supports this conclusion.

The higher specific gravity of apatite (3.10 - 3.35 compared with 2.63, 2.65 and 2.76, and 2.55 - 2.63 for quartz, albite, anorthite and orthoclase respectively) means that it is probably not transported by wind as far nor as high as other minerals of similar size, another factor which no doubt helps to account for the decrease in Pa as a % of Pinorg with increasing altitude. This is reflected in the lower P_T levels in loess derived soils compared with those derived from greywacke colluvium (discussed in the next section, see Appendices 1 and 3). Conversely, fine fractions contain greater amounts of non-occluded (surface Al - P and Fe - P) and occluded phosphorus (Shah et al 1968, Syers et al 1969) than amounts of Ca - P and this feature may tend to complement differences noted above.

Very low levels of exchangeable bases and low base saturations (BS %) of some of these loess derived soils, notably the Sherwood and Kakahu hill soils, are indicative of a much greater degree of leaching than is suggested by either the climate, morphology, or history of these soils. An obvious explanation is the inclusion, within the loessial material, of previously weathered (and leached) soil materials. Consequently it is difficult to assess the actual degree to which these soils have been leached as the parent loess probably contained both fresh, recently comminuted material and pre-weathered and leached material.

Similarly, without reference to the original nature of the parent loess it is difficult to estimate the contribution made by the parent loess to the clay mineralogy of these soils. The presence of metahalloysite in all of these soils indicates a weathering stage in advance of that considered normal for the zone (Fieldes 1961 and in Soil Bureau Staff 1968b). Fieldes in Soil Bureau Staff (1968b) has noted the occurrence of a "stage 3" kaolin mineral in the Marton silt loam, a yellow-grey earth, and has suggested a derivation from the parent material. Syers et al (in press) have noted the presence of kaolinite in the silt and sand fractions of the strongly weathered greywacke rock sample underlying the Rangiora silty clay loam. The kaolinite was formed as a weathering product from feldspar phenocrysts and increased with the degree of weathering of the greywacke rocks. They noted, however, that the kaolinite became dispersed in the solum, a consequence of pedogenic reorganisation, and formed only a small percentage of the coarser fraction of the fine earth.

The metahalloysite content is higher in those soils which have weathering rocks in the lower solum, but still forms an appreciable amount of the crystalline clay fraction of the upper solum of those soils and also in soils formed from younger loess over older loess deposits. Its persistence in these latter soils and the similarity of amount in the upper parts of all of these soils suggests that in the younger loess deposit it may be derived as such from the erosion products of a previously weathered soil.

Certainly if such is the case it is more than probable that other clay minerals have been similarly derived. Possibly included in this assumption are the interlayered-chlorites which also form an appreciable part of the crystalline clay fraction. Witchalls (1969) considered that these intergrades indicated an advanced stage of weathering in some of the yellow-brown earths of Otago and Southland and if this is so, along with metahalloysite indicate weathering in advance of that usual for the zone in which the Mowbray catchment lies. To consider their inheritance as part of the loess complex deriving from older, now eroded soils, is a logical assumption which offers a simple and straight forward answer to the problem. A more detailed examination of this matter is presented in the ensuing section.

B. The effect of topography - Topography as it is manifested in the features of aspect, exposure and ground water has also exerted an influence on the soils derived from loess. Aspect in relation to the source of loess has been particularly significant. Using the depth of solum as the principal criterion, loess seems to have accumulated to the greatest depths on northwesterly facing slopes and on northeast through to southeasterly aspects.

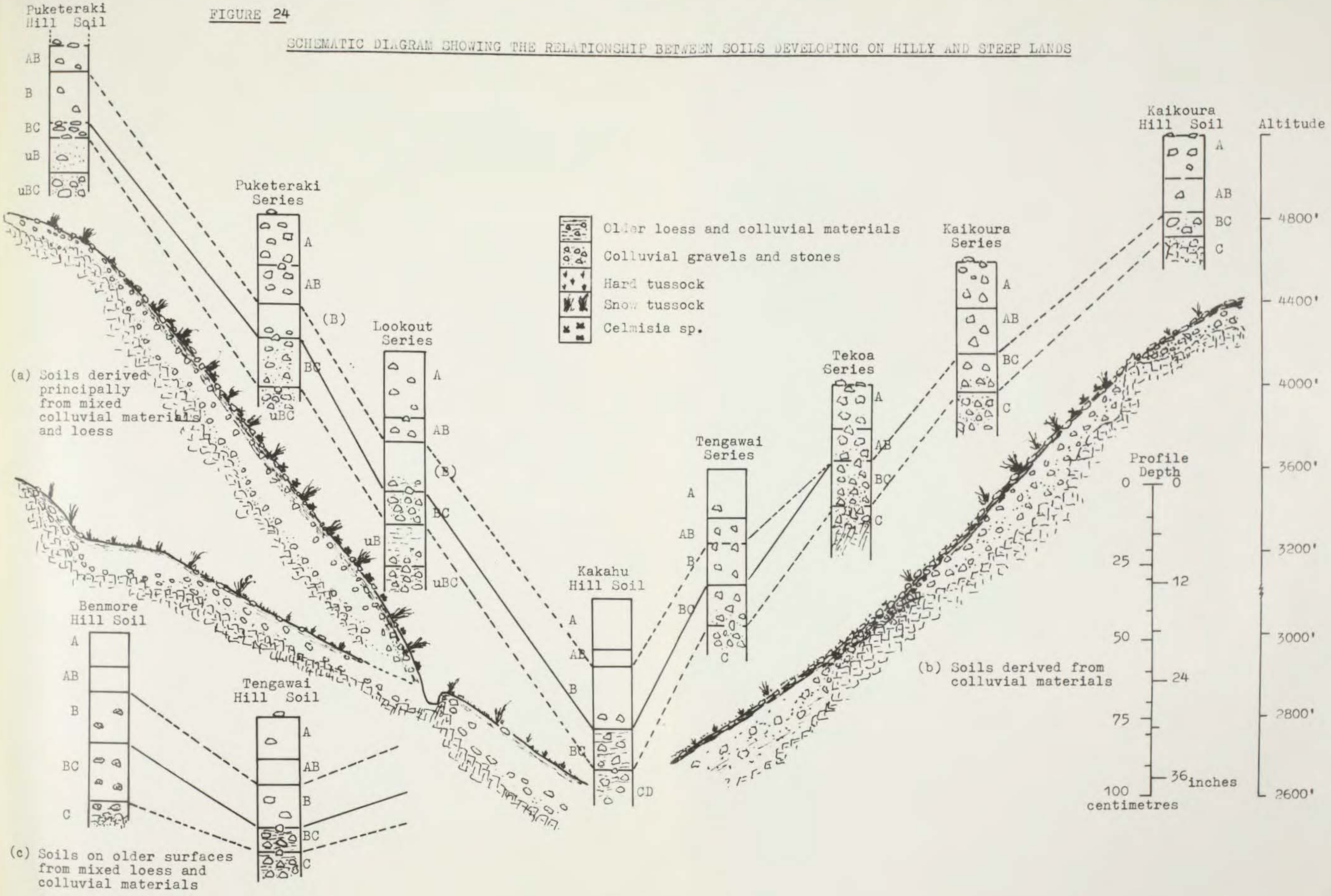
Southeasterly aspects, despite higher annual moisture, show less morphological development than soils on other aspects. This probably results from the lower annual temperatures experienced by these sites; a direct result of lower insolation. On the other hand, Tengawai hill soils, although receiving higher rainfall than that experienced at lower elevations, occur in very exposed sites and as a result suffer seasonal dryness. Consequently, they display distinct yellow-grey earth characteristics.

Pale subsoil colours, strong mottling and coarse blocky structures are features of the Skipton and Clayton series which can be attributed to seasonally high standing ground water levels, or the occurrence of perched water tables.

On exposed faces at higher altitudes, where the Kakahu hill soils commonly occur, colder winter temperatures and the moister soil conditions due to the slightly higher rainfall prevail. Due to these conditions such sites sometimes show solifluction terracettes. In these locations, as a result of this activity, (also a feature of the drift regime) soil development tends to be retarded. Fresh material enters the solum from below and gradual downslope movement

FIGURE 24

SCHEMATIC DIAGRAM SHOWING THE RELATIONSHIP BETWEEN SOILS DEVELOPING ON HILLY AND STEEP LANDS



tends to destroy acquired horizon characteristics.

3. SOILS OF THE HILLY AND STEEP HILLSIDES

(a) Inferences from morphology and site factors - These soils include the high country yellow brown earths, the Lookout, Puketeraki, Tekoa, Kaikoura and Kirkliston series and their related hill soils and the Tengawai series - a yellow grey earth. They fall into three main classes on a parent material basis:

i. soils derived from mixed loess and colluvial materials;

ii. soils derived from predominantly greywacke colluvial material or on greywacke rock in place; and

iii. strongly developed soils on old deeply weathered loess and colluvial deposits.

These may be considered as two sub-suites, class iii. contains only one member and may represent the ultimate stage of development of either or both sub-suites.

Kirkliston series occur on old mixed loess and colluvial materials (Class iii) which probably originated in pre-Otiran times. Gair (1962) has suggested a comparative age for an apparent exhumed surface on Blue Mountain and it is probable that the small area of Kirkliston soils in the survey area are a residual part of this surface. Morphologically, with the moderately deep profile, bright B horizon colours and strong structures, and strongly decomposing greywacke fragments in the lower solum, these soils represent a stage of weathering far in advance of that attained by other high country yellow brown earths encountered during this survey. They conform with the modal concept of dry hygrous eldefulvic soils and probably represent the normal weathering/leaching progression for the drier end of the high country yellow brown earth range.

The key factors in their development have been, relative stability and the length of time over which the agencies of weathering and leaching have operated. Because of the wide difference in age between these soils and the other high country yellow-brown earths in the catchment they are mentioned separately and the following discussion concerning the genesis of the younger soils does not include the Kirkliston series.

Amongst the other high country yellow brown earths two developmental sequences can be traced in the upper basin. They are characterised primarily by the nature of the parent material. In general the development of these high country yellow brown earths increases with increasing altitude and rainfall and/or decreasing slope. At lower altitudes on the other hand and under slightly drier conditions, they can be related to steepland yellow grey earths and soils developed from loess over loess and colluvium. Figure 24 shows a schematic arrangement of soils in this environment, in relation to topography - vegetation and parent material. Diagramatically, Figure 25 shows the idealised developmental sequences of the two sub-suites on a morphological basis.

The unifying factor is one of colluviation. Generally the soils in lower slope locations are affected by relatively active accumulation of material. In upper slope locations the removal of material from the surface and mixing within the solum is not great enough to destroy the processes tending to form soil horizons. The positioning of the Puketeraki hill soils between the Puketeraki and Lookout soils does not conform exactly with the proposed altitudinal sequence. This is a result of the effects of recent truncation on the morphology of the only Puketeraki hill soil profile examined.

Lookout, and Puketeraki series are developed over deposits of mixed loess and colluvial materials and almost invariably overlie the lower solum of an older soil derived from mixed loess and colluvial materials. They have a better vegetation cover than soils developed

SCHEMATIC ARRANGEMENT OF SOILS ON HILLY AND STEEP LANDS
TO INDICATE TRENDS IN SOIL DEVELOPMENT

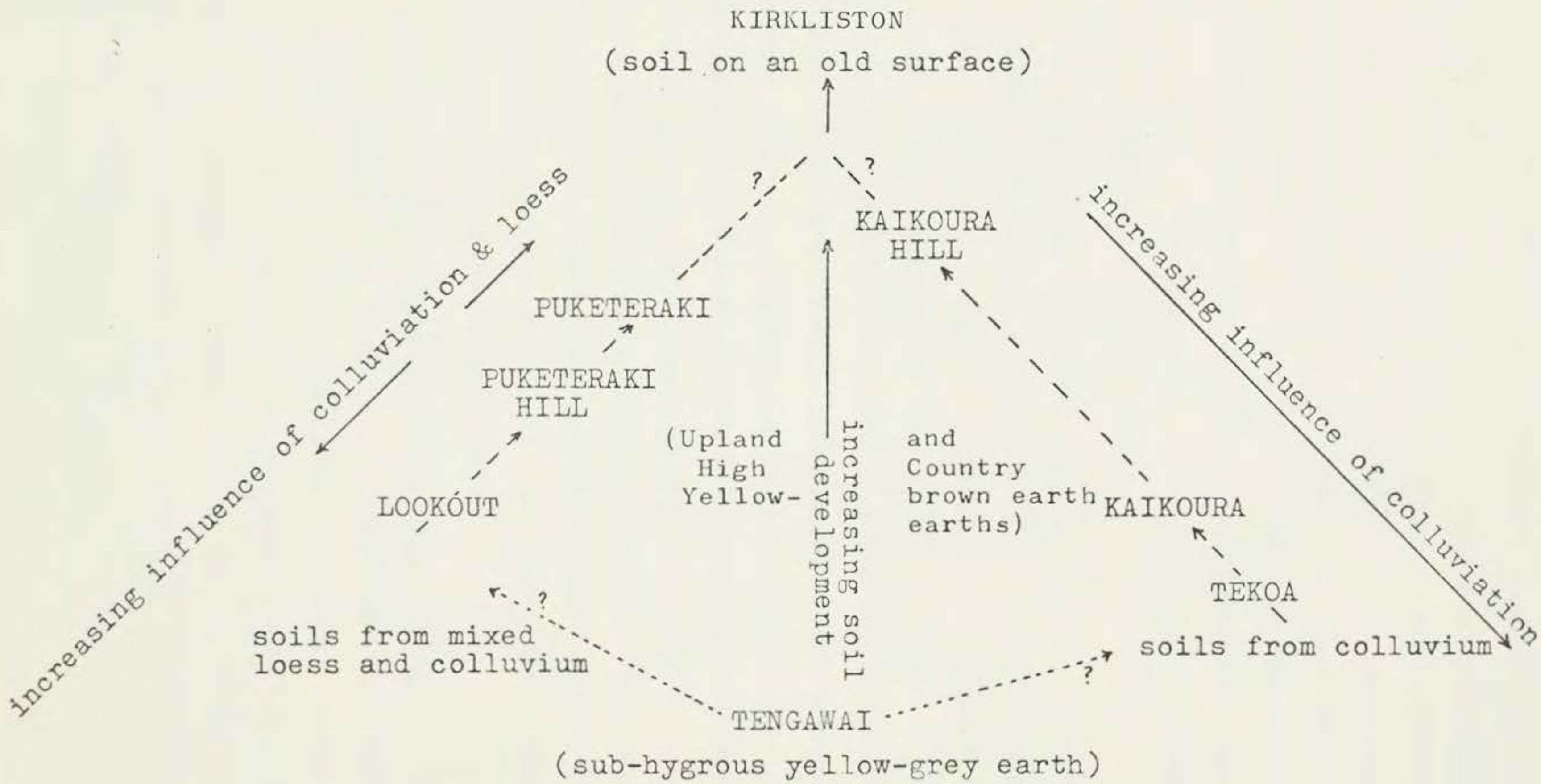


Figure 25

on one cycle colluvium and are generally confined to southeastern to southwestern aspects. The better, present vegetative cover, residual from preferential burning and grazing has probably induced greater stability in these soils particularly in more recent times. The vegetation has tended to trap fines blown and washed off adjacent, barer slopes thus emphasizing contrasts between the soils of this class (i) and those of class (ii). The greater proportion of fines, probably pre-weathered and the cooler moister aspects have given rise to the paler colours, lower pH and base status characteristic of the soils of this class.

The soils (sub-suite - Class (ii)) developed on greywacke colluvium and greywacke rock in place form a definite sequence of development which relates directly to the rate of accumulation of surficial material. In contrast to the soils of class (i) where colours in the (B) horizons have a 2.5Y hue and values of 5 or 6, the soils of class (ii) have lower solum colours which range from brown to yellowish brown (hue 10YR and values 4 to 5) through the sub-suite from the weakly developed Tekoa series to the moderately developed Kaikoura hill soils. These changes follow changes in increasing altitude and decreasing angle of slope. Greater exposure, drier aspects and poorer vegetative cover are the main features which have contributed to the more skeliform appearance of these soils, as compared with the soils of class (i).

(b) Inferences from chemistry and mineralogy - The chemical and mineralogical features of these soils conform very closely with the proposed morphological sequences of development. Figure 20 shows the changes in absolute amount, and as percentages of P_T, or the various phosphorus fractions. These trends, which conform with those outlined by Walker (1965) (Figure 19) complement the deduced morphological sequences.

However, the high proportion of total P which occurs as Pf in weakly weathered soils of the two sequences, particularly in the Tekoa series (Figure 20) does not conform well with the idealised proportion of P fractions suggested for the early stages of soil development by Walker (1965). The acquisition, by either aerial accretion or down-slope movement of a pre-weathered fine fraction is a possible explanation of this anomaly. On the other hand, the presence of a high proportion of included apatite which is released from inside less soluble minerals with increasing development (Syers et al 1967) (Syers et al in press) is a considered alternative. Also the observation of Syers et al (1969) that the rate of shift of non-occluded secondary phosphorus to occluded forms kept pace with the rate of formation of non-occluded P in relatively weakly weathered (admittedly) alluvial soils, is worthy of note.

This latter explanation is particularly significant in the light of recent work by Syers et al (in press) which showed a high proportion of occluded - P relative to non-occluded - P in the weakly and moderately weathered greywacke parent rock of the Rangiora silty clay loam. The lower clay content of the Tekoa profile relative to its position in the suggested developmental sequence, and the high P_T levels in relation to the total phosphorus content of the parent rock:

A_1	312	)
AB	510	)
BC	472	) Kg/ha/profile inch
Weakly weathered argillite from the BC	580	)

indicative of weak leaching and development, would tend to support the second explanation proposed above. Minor effects due to accretion of pre-weathered fine material and the rapid transformation of non-occluded to occluded - P, however, should not be discounted.

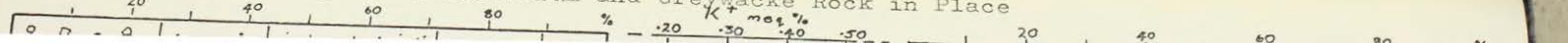
By extrapolation it may be assumed that in the soils of both the sequences a large proportion of the Pf fraction may exist as residual inorganic - P which includes both included Ca - P, probably the larger part in these soils, and strongly occluded Al - P and Fe - P. The former being found in the coarser fine earth component (coarse silt and sand fractions) and probably derived directly from rock breaking as a result of colluviation. Consequently, changes in the Pa fraction as a proportion of P_T give give a more reliable index of soil development amongst both sequences. And, by the same token, the variations in the proportion of Pf relative to the sand and coarse earth fraction is indicative of the significance of the processes of the drift regime, particularly colluviation, in the formation of these soils. That is, as illustrated in Figure 26, Pa and Pf as a percentage of P_T, in general, respectively decline and increase with an increase in the sand fraction.

The trends apparent in the changes in levels of exchangeable cations and total bases reflect the proposed developmental sequence. With increasing profile depth there is a progressive loss of exchangeable bases in five out of eight sets of determinations - exceptions are the profiles MC 69 (Puketeraki series), MC 70 (Kaikoura series) and MC 77 (Tekoa series). The former two soils are developed over deep colluvial debris and an increase in base status in the BC horizons reflects the less weathered and leached nature of the coarse component. The Tekoa series are skeletal intergrades to high country yellow brown earths and the progressive increase in base status is what would be expected for such soils (see Figure 22).

The decrease in base status with increasing depth of the Kaikoura hill soils is indicative of the deep weathering and

Figure 26 - Changes in Basic Chemistry, particle size fractions and crystalline clay mineral transformations with increasing soil development of soils from mixed loess and colluvium and soils developing over colluvium and greywacke rock in place.
(Based on averages for whole of current profiles)

A. Soils Developing on Colluvium and Greywacke Rock in Place



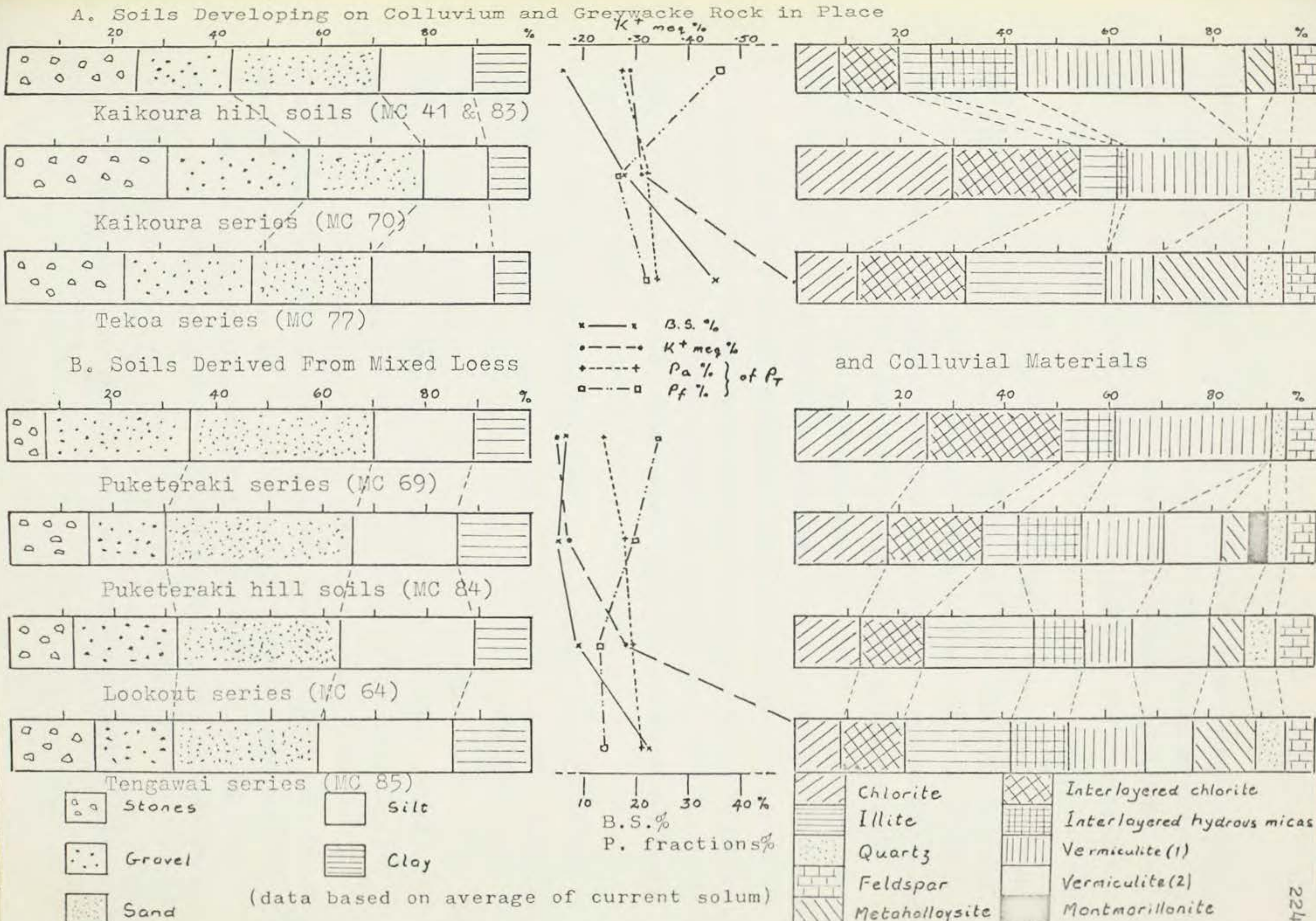

A. Soils Developing on Colluvium and Greywacke Rock in Place
20
40
60
80
%
K^+ meq %
·20
·30
·40
·50
Kaikoura hill soils (MC 41 & 83)
Kaikoura series (MC 70)
Tekoa series (MC 77)
B.S. %
K^+ meq %
P_a %
P_f % } of P_T
B. Soils Derived From Mixed Loess
and Colluvial Materials
Puketeraki series (MC 69)
Puketeraki hill soils (MC 84)
Lookout series (MC 64)
Tengawai series (MC 85)
10
20
30
40 %
B.S.%
P. fractions%
Stones
Silt
Gravel
Clay
Sand
(data based on average of current solum)
Chlorite
Illite
Quartz
Feldspar
Metahalloysite
Interlayered chlorite
Interlayered hydrous micas
Vermiculite (1)
Vermiculite (2)
Montmorillonite

Figure 26

leaching which has affected the more stable ridge crest soils. This stronger leaching is also reflected in the buried part - profiles which are found at lower levels beneath currently developing soils of the Lookout series (MC 64) and Puketeraki (MC 84) hill soils.

Figure 22 shows the strong contrast in base status between the recent skeliform Tekoa series and the very strongly leached Puketeraki series. Soils grouped as being derived from mixed loess and colluvial materials (sub-suite from class i) are more strongly leached than their counterparts developed over colluvium and greywacke rock in place (sub-suite from class ii). This is due to a combination of the moister environment on more sheltered aspects, and the admixture of pre-weathered wash and windblown fines which characterise the former group while the more pronounced effects of colluviation, and hence reduced stability, tend to introduce less weathered material, from below, into the solum of the soils of sub-suite (ii).

There is a progressive loss of micaceous minerals in the crystalline clay fraction of both sub-suites. Figure 26 indicates a progressive weathering trend which conforms with morphological and chemical assessment. There is a corresponding increase in clay-vermiculites which tends to complement this proposed weathering sequence. A progressive increase in chlorite and interlayered chlorites as a percentage of the crystalline clay fraction is demonstrated by the sub-suite (i), the soils of which are derived from mixed loess and colluvial materials. These trends may be extended to show a lesser stage of development in the Tengawai series - a yellow grey earth (as illustrated by profile MC 85 - Figure 26).

Primary chlorite occurs as a minor constituent of greywacke

(Reed 1957, Fieldes and Weatherhead in Soil Bureau Staff 1968b). Jackson (1964) records a weathering index of (4) for primary chlorite and has noted that under normal weathering conditions primary chlorite forms a secondary (Fe, Mg, Al) chlorite (Jackson 1964 and Dixon and Jackson 1962). This is a separate and distinct mineral from Al - chlorite (Jackson 1964) which forms by the progressive alumination of pedogenic intergrades resulting from the alumination of vermiculite and secondary chlorite (Jackson 1965).

Primary chlorite, particularly where Fe is the dominant cation, on X-ray diffraction has a second order (002) peak at 7.0 Å to 7.2 Å which is more intense than the first order peak at 14 Å (Brown p. 261 1961), (Campbell pers comm). On weathering the 7.0 Å to 7.2 Å peak becomes less intense. An X-ray powder diffractogram of unweathered greywacke shows a sharp intense 7.1 Å and a weak 14 Å peak. Diffractograms of weathered greywacke rocks from the D and C horizons respectively of profiles MC 44 (Tengawai hill soil) and MC 70 (Kaikoura series) show weak 7.1 Å to 7.2 Å peaks and distinct, strong 14 Å peaks. A possible interpretation is that primary chlorite weathers fairly rapidly, even within the fabric of arenaceous rocks, and as a consequence, the bulk of the chlorite identified in the clay fraction by its heat stability following K+ saturation, is the secondary (Fe, Mg, Al) chlorite (Jackson 1964). Syers et al (in press) also noted that weathering stages in advance of secondary chlorite and hydrous micas were present in strongly weathered greywacke from North Auckland.

Acceptance of the idea that the bulk of the 2:2 clay identified in the clay fraction is secondary (Fe, Mg, Al) chlorite (Jackson 1964), hereafter called <u>pedogenic chlorite</u>, inherited from the weathering of primary chlorite in the coarser fractions of the soils, enables the postulation of a chloritic weathering sequence, similar to the micaceous weathering sequence and corresponding to that proposed by Jackson (1964). Earlier, Jackson (1959) considered that pedogenic chlorite could be formed from the interlaying of micas with positively charged Al, Fe and/or Mg hydroxides. Such a sequence is apparent in those soils derived from mixed loess and colluvium (class i). Pedogenic chlorite increases with increasing weathering of primary chlorite in the coarser components of the fine earth, and in turn forms 2:1 to 2:2 layer silicate pedogenic intergrades, in a similar fashion to that outlined by Jackson (1964 and 1965). These 2:1 to 2:2 intergrades also appear to form at the expense of micaceous material as the increase in the proportion of clay-vermiculite does not follow the reduction in percentage of illite and interlayered hydrous micas.

The transformations from micaceous and chlorite minerals to the two vermiculite forms identified, according to Fieldes (1968) and Claridge (1969), is more obscure, and a reconsideration of these two forms is necessary. Jackson (1965) recorded equations showing the formation of dioctahedral vermiculite* of high charge from dioctahedral muscovite in the presence of free Ca^{2+} ions. In the presence of hydroxy-alumina or hydroxy-iron ions high charge vermiculite was shown to form acid alumina - or iron-vermiculite. However, Jackson has never attempted to correlate the vermiculite of his proposed weathering sequence (1964) with the clay-vermiculite observed by Fieldes.

Arnold (1966) pointed out in his review that acid vermiculite would have the lower layer charge of the two forms of Jackson (1965).

* Fieldes noted (1961) and (1968) that the clay-vermiculites in New Zealand soils were dominantly dioctahedral.

Fieldes (1968 p. 26) noted that clay-vermiculite (2) has lower amounts of layer charge than clay-vermiculite (1), but has nowhere shown any analogy between these two forms of clay-vermiculite and those discussed by Jackson (1965). Fieldes (1962) has indicated, however, that the difference between the two forms, clay-vermiculite (1) and (2) is dependent upon the degree and extent of chlorite-like interlayering of hydroxy alumina, clay-vermiculite (2) displaying the less extensive interlayering of the two forms.

Fieldes and Swindale (1954), Fieldes (1962) and (1968) have indicated that clay-vermiculite (2) tends to form under conditions of higher levels of exchangeable Ca^{2+} (and/or Mg^{2+}) than clay-vermiculite (1), and with continued weathering under such conditions, gradually forms montmorillonite.

Jackson (1964 p. 121) has noted that vermiculite can weather to montmorillonite in an acid environment while (and after) being interlayered. He also writes on the next page, " ... montmorillonite can persist in highly montmorillonitic soils long after the soils become acid ...". Thus montmorillonitic structures in clays can result from either the complete replacement of K^+ ions in micaceous structures by Mg^{2+} (or Ca^{2+}) or by the intensive interlayering with hydroxy-alumina layers and subsequent silicification (Jackson 1964), the former case in more basic environments and the latter by alumination and silification in acid environments (Jackson 1965 p. 18).

Clay-vermiculite (2) may then be considered to weather progressively to montmorillonite in the less acid or near neutral environments following the replacement of interlayered K^+ ions of hydrous micas by hydroxy alumina. Stronger alumination would result in further interlayering of clay-vermiculite (1) with hydroxy alumina - the "anti-gibbsite effect" (Jackson 1964 p. 124) -

tending to form 2:1 to 2:2 pedogenic intergrades. More intense alumination and desilication in such environments leading to the formation of 1:1 type clay minerals and eventually gibbsite. It is probable then that vermiculite of Jackson's weathering sequence corresponds to clay-vermiculite (2) of Fieldes and the group of minerals designated as 2:1 to 2:2 pedogenic intergrades (Jackson 1964 pp 102 and 104) include both clay-vermiculite (1) and inter-layered chlorites of Fieldes.

The pHs of these moderately to very strongly enleached soils on hilly and steep hillsides ranges between 4.9 and 5.7 with an average pH of 5.1 - 5.2 for those soils on mixed loess and colluvial materials (class i) and 5.3 - 5.5 for soils derived from colluvial materials or greywacke rock in place (class ii). In such environments it is unlikely that clay-vermiculite (2) would be actively forming, and less likely that montmorillonite would form other than as a result of clay-vermiculites acquiring 18 Å basal spacing following silication of acquired hydroxy alumina interlayers (Jackson 1965 p. 19). Consequently, the course of micaceous weathering is probably from hydrous micas to vermiculite (1) or pedogenic 2:1 to 2:2 intergrades. While it is unlikely that clay-vermiculite (2) as envisaged by Fieldes is being formed under present conditions, it is possible to envisage a progressive sequence with clay-vermiculite (2) forming from the expansion of micas, transforming rapidly to clay-vermiculite (1) with the acquisition of chlorite-like hydroxy-alumina interlayers.

Consequently one must find an alternative explanation to account for the variable occurrence of clay-vermiculite (2) in these soils. Clay-vermiculite (2) has been found as one of the major constituents of the yellow grey earths (Fieldes 1962, 1968) and it is not unreasonable to suppose that to a large degree this mineral has been derived directly from the accumulation of wind blown fines eroded from the drier soils at lower elevations. This is in keeping with the two sub-suites of soils on hilly and steeplands since those soils of class i have larger amounts of clay-vermiculite (2) than those soils of class ii.

Such an explanation could also account for the presence of montmorillonite in the buried horizons of the Puketeraki hill soil (MC 84). The source of wind blown material could be the Geraldine-Kakahu area, southeast of the Mowbray, where soils derived from Ca-rich parent materials occur (Raeside et al 1959). Also, montmorillonite which occurs in the Puketeraki silt loam at the "reference site" (Soil Bureau Staff 1968b) could be of similar origin, since the limestones of the Castle Hill basin are only a short distance to the west (the direction of the prevailing wind) of this site. The possibility, however, that silication of some of the hydroxy-alumina interlayers of the 2:1 to 2:2 intergrades is occurring cannot be completely discounted.

It is difficult to determine whether the metahalloysite and gibbsite observed in these soils on hilly and steeplands of the Mowbray catchment is currently forming. Fieldes and Swindale (1954), Fieldes and Taylor (1961), Fieldes (1962), and Jackson (1964) have indicated that under acid conditions clay-vermiculites weather to form 1:1 clay minerals and eventually gibbsite. Jackson (1964) notes that to reach such stages, weathering of micaceous and chloritic minerals gives rise to Al chlorites. As it has not been possible to separate Al chlorite which may be present from pedogenic chlorite by X-ray diffraction techniques, it is not possible to say if these soils have reached such an advanced stage of weathering. It is more logical, however, to envisage the formation of metahalloysite from the weathering of feldspars.

Jackson (1964 p. 108) noted that halloysite can be formed from extremely small particles of allophane by crystallisation, and by weathering of feldspathic rocks, and later (page 111) he recorded:

" ... amorphous aluminum and iron oxides become stabilised by silica only temporarily in the form allophane. With time and weathering the two crystalline phases halloysite and gibbsite frequently separate out ...".

Fieldes and Swindale (1954) noted that once amorphous hydrous oxides had been formed,resilication to kaolin and its forms is relatively rapid. Feldspars, however, were considered to be relatively resistant to weathering,only slowly forming amorphous hydrous oxides. The positive reaction to the allophane field test (Fieldes and Perrott 1966) noted in the soils on hilly and steeplands of the Mowbray catchment indicated that amorphous hydrous oxides are being released by the weathering of alumino-silicates. Consequently, it is probable that the crystallisation of metahalloysite and gibbsite is taking place. Whether metahalloysite has formed to the extent indicated by the intensity of the 7.4 Å peak (Fieldes 1968, Claridge 1969) is debatable. More logically, those soils having a high metahalloysite content have probably inherited a large part of that mineral from a previous weathering cycle as a result of the activity of the drift regime.

(c) Major influences in soil formation - The effects of an active drift regime and the influences exerted on the processes of the drift regime by the factor topography and sub-factor vegetation are the chief criteria which have determined the nature of the soils formed on the hilly and steep lands. Influences resulting from events during the later Quarternary history, particularly those directly attributable to man, and the nature of the parent material and climate have had a profound effect on these soils, but only in the way in which they have either complemented or reduced the effects of the influences exerted by the drift regime, topography and vegetation.

A. The effect of the drift regime - The drift regime has been and is currently still active in areas covered by these soils. It is manifested in the effects of:

i. accumulation, by wind and gravity;
ii. soil erosion, both normal and accelerated;
iii. soil mixing by creep and solifluction;
iv. renewal of the mineral skeleton by the introduction of less weathered components from the underlying proximate parent rock.

The accumulation of finer material following wind transport is particularly marked in those soils developed from mixed loess and colluvium. Accumulation of coarser material following slope-wash and gravity movement is seen in the upper horizons of soils developed in mid and lower slope locations. Colluviation of these slopes has probably been effected by creep erosion. Soil creep and solifluction are the main forms of activity on slopes covered with mixed loess and colluvial debris, whilst scree creep, soil creep and solifluction all contribute to the movement of material on the more exposed slopes where colluvial debris predominates (Figure 28).

The movement of finer material by running water is an ever present phenomena amongst soils on inclined surfaces. Where the removal of material is slow, the introduction of fresh material from the underlying parent rock keeps pace with removal. Breaking and decay of coarse rock fragments within the profile, however, may not keep pace with the removal or eluviation of the finer components from the surface horizons. When this occurs there is a tendency for coarser material to concentrate in the upper horizons of the profile. A situation such as this can be grossly exaggerated by accelerated erosion. Plates 13 to 15 illustrate to a large extent the effects of slightly accelerated erosion. Where fire or animals have induced severe devegetation, accelerated erosion has occurred. The upper part of the regolith moves by scree creep. Downslope movement, coupled with winter freeze and thaw cycles, induces deep mixing of this part of the regolith. To a limited extent, mixing of the upper part of the regolith of soils developed principally from mixed loess and colluvium also occurs under the influence of gravity and freeze and thaw cycles.

A situation then exists, whereby soil creep, and to a lesser extent solifluction, and normal to slightly accelerated erosion, has brought about an increase in the coarse component of the upper horizons of certain soils (see description of Puketeraki stony silt loam MC 69 in Appendix 1). These are principally soils from mixed loess and colluvium and are found in better vegetated sites. In regions of depleted vegetation more severe erosion has caused a greater concentration of coarse fragments in the upper part of the profile (e.g. Tekoa series, Kaikoura hill soils). Mixing brought about by a more rapid form of soil creep, scree creep and probably solifluction has led to profiles with a more even distribution of the coarse component throughout the solum (see MC 70 Kaikoura steepland soil). These latter zones give rise to soils derived principally from colluvium. The removal of material by wind erosion from bared surfaces and the deposition in the better vegetated regions, where the chances of entrapment are greater, has also tended to accentuate differences between the two sub-suites, as outlined above.

It is also possible that during colder periods, when winters have been more severe than normal, freeze and thaw cycles may have resulted in the formation of layers with coarser components over layers (or horizons) dominated by fine earth fractions. Ragg and Bibby (1966) considered that such phenomena - stone lift due to freezing of soil moisture in the upper layers of the solum followed by washing of fines into the voids, so created, during the ensuing period thaw - were responsible for layering in soils and associated regolith at 1800 to 2000 ft above sea level in the southern uplands of Scotland. Lift and rafting of stones, by needle ice, has been observed by Hayward (pers comm) on bare stone pavements at 3500 ft at Porters Pass but it is debatable how marked the effects of such phenomena would be under a moderately extensive vegetation cover in the drier climatic zone occupied by the Mowbray catchment.

It becomes apparent then that the stage of development which a soil at any site attains is dependent to a large extent on these influences of the Drift Regime. The removal of material by erosion, the introduction of fresh material from the lower solum and mixing associated with gravity movement are all influences which tend to prevent a soil reaching more advanced stages of formation. Accumulation of previously weathered windborne, slopewash and colluvial materials is an influence which tends to advance the stage of development beyond that indicated by normal soil formation on stable sites. Consequently an understanding of the operative processes is a necessary pre-requisite to the interpretation of the genesis of soils on hilly and steep slopes.

B. The effect of topography - Topography, particularly the facets of aspect, exposure and angle of slope has had a marked influence on the genesis of soils on hilly and steep lands.

Principally, however, it is the geomorphic relationship of any site with adjacent areas which exerts the greatest influence - a feature also observed by Cutler (1962). An apparently stable site of moderate slope may be influenced by an active drift cycle from a more strongly sloping surface in an up-slope location. Runoff following snow-melt on an exposed surface may have a marked effect on sites in sheltered aspects at lower elevations.

Generally the stabilising influence of loessial accumulation decreases with increasing altitude and slope and the effects of movement conversely increase with increasing altitude and slope (Figure 27). On more sheltered aspects the regolith tends to display a greater degree of stability than that seen on less sheltered, more exposed aspects. Broad ridge crests of moderate slope, but extremely exposed, may owe the existence of stony topsoils to the effects of wind erosion - removing the fines and concentrating the coarse earth. On the other hand, however, the possibility of layering due to freeze and thaw cycles should not be overlooked. Probably, both processes are active, the former during the dry summer months and the latter during winter and spring.

C. Influences due to vegetation - Vegetation, either by its presence or absence has had a profound effect on the formation of the soils on hilly and steep lands of the Mowbray catchment; as in fact it has on the majority of steepland soils (Cutler 1962, Molloy 1964, Vucetich 1968). Removal of the stabilising influence of vegetation, certainly following man's occupation of the country, and probably due to natural fires in earlier periods, has allowed topography and the drift regime to exert their influences on the formation of soils to a much greater degree than had occurred in previous times. Soils within this category with a more continuous cover, found on the more sheltered aspects (and consequently moister) display deeper more stable profiles. The stabilising effect of vegetation is particularly apparent in Figure 9 and Plate 14.

Coupled with the influences due to vegetation are the related effects produced by climate and parent material. Precipitation increases with increasing altitude, and in general, slope. The barer the surface, however, the less effective the precipitation due to losses by greater runoff and potential evapotranspiration. The protective covering of vegetation reduces moisture loss and as such provides an environment more conducive to weathering and soil formation. However, amongst these soils vegetation cover is greatest on the more sheltered aspects and consequently the reduced temperatures of such sites tend to reduce contrasts between well vegetated and sparsely vegetated sites.

The overall similarity of the parent material and the contribution of pre-weathered particles from the atmosphere and by slope wash, and the time during which current soil forming processes have been operating, tend to reduce expected weathering contrasts between these soils. It is because of such limitations that these soils on hilly and steeplands have been considered as two separate, parallel sequences (or sub-suites) with closely related stages. The members of each sequence being related on the basis of like morphological characteristics and like topographic relationships.

D. Summary - These factors of the environment can be related to general trends apparent in the chemistry and mineralogy of the soils on hilly and steeplands:

i. Pf increases as a % of P_T with an increase in the sand and coarse silt component;

ii. the sand and coarse earth component reaches a maximum in both sub-suites in soils in mid-slope and upper mid-slope locations - a result of topographic variation

(Figure 27) and the activity of the drift regime - also noted by Franzmeier et al (1969);

iii. leaching increases with increasing altitude as does the amount of weathered 10 Å micaceous clays - a result of the influences of the climate and the contribution of partially weathered minerals from the coarse silt and sand, and coarse earth fractions;

iv. an increase in clay content at higher altitudes and with decreasing slope (Figure 27) is indicative of greater stability and weathering in such sites relative to the steep hillsides;

v. the appearance of minerals indicative of stages of weathering in advance of that indicated by the more stable soils of higher clay content, is construed as evidence of the activity of the drift regime in providing pre-weathered components from previous cycles within the area and from external sources.

4. MAJOR INFLUENCES IN THE FORMATION OF SOILS IN THE MOWBRAY CATCHMENT

The greatest influences exerted on the soils of the Mowbray area are those of the "Inorganic Cycle" or Drift Regime (Soil Bureau Staff 1968b), particularly accumulation, removal and mixing. The processes of the "Wasting Regime" are only apparent in recent soils from alluvium and in shallow and stony soils on steep slopes.

(1) The Influences of the Drift Regime

All of the main processes of the "Drift Regime" have been operative in the formation of the soils of this area. The foregoing discussion summarised in Figure 28 illustrates this point. The influences exerted by accumulation, mixing (due to either (i) colluviation - the mixing of slope debris deposits by soil or scree creep or solifluction or any combination of these and

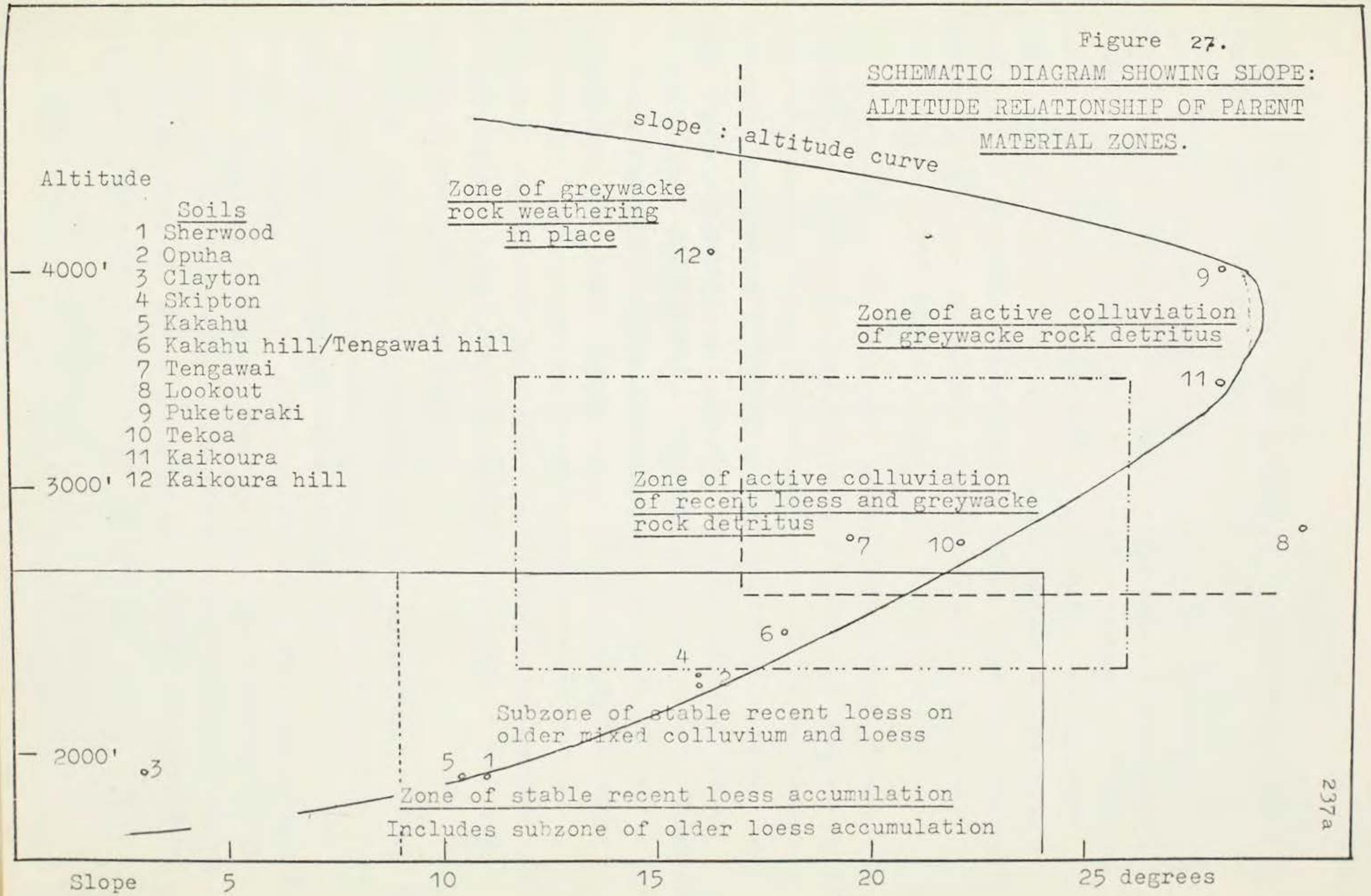


Figure 27.
SCHEMATIC DIAGRAM SHOWING SLOPE:
ALTITUDE RELATIONSHIP OF PARENT
MATERIAL ZONES.
slope : altitude curve
Altitude
Soils
1 Sherwood
2 Opuha
3 Clayton
4 Skipton
5 Kakahu
6 Kakahu hill/Tengawai hill
7 Tengawai
8 Lookout
9 Puketeraki
10 Tekoa
11 Kaikoura
12 Kaikoura hill
4000'
3000'
2000'
Zone of greywacke rock weathering in place
Zone of active colluviation of greywacke rock detritus
Zone of active colluviation of recent loess and greywacke rock detritus
Subzone of stable recent loess on older mixed colluvium and loess
Zone of stable recent loess accumulation
Includes subzone of older loess accumulation
12
9
11
7
10
8
6
4
2
5
1
3
Slope
5
10
15
20
25 degrees

aided by freeze and thaw cycles, and (ii) wetting and drying cycles) and erosion are by far the most significant.

(a) The role of loess in soil formation - Loess has accumulated to varying depths over a large area of the Mowbray catchment. It has accumulated as layers on deposits of alluvium, loess, mixed loess and slope debris and has been incorporated with slope detritus on actively colluviated slopes. On more stable sites loess has accumulated in recent times to a depth of between 16" and 24" and shows a progressive shallowing with increasing slope and altitude above 2200 ft (Figure 29).

The loess of the catchment is probably of mixed origin. It includes fresh material resulting from the physical comminution of stones and gravels during riverbed erosion, and pre-weathered material from eroding hillsides and terraces of the Mowbray and upper Orari catchments, and probably from the adjacent upper Fairlie basin. Consequently, even at the initial time of deposition the loess could contribute materials, part of which were fresh and unweathered, and partly displaying evidence of advanced stages of weathering. Such variations in the parent material must be invoked to account for the anomalies in chemical and mineralogical characteristics which cannot be explained in terms of simple morphological weathering sequences.

(b) The role of colluviation in soil formation - "Colluviation" as used herein means the intimate mixing of rock debris with soil material within the regolith on hill slopes as a result of the erosive processes of soil creep, solifluction and scree creep and commonly aided by freeze and thaw cycles. The processes of creep erosion are used according to the definitions outlined by Taylor and Pohlen (1962 pp. 60-61) and also conform with the phenomena outlined by Leopold et al (1964 pp. 344-51).

FEATURES OF THE DRIFT REGIME EFFECTIVE ON DIFFERENT TERRAIN TYPES

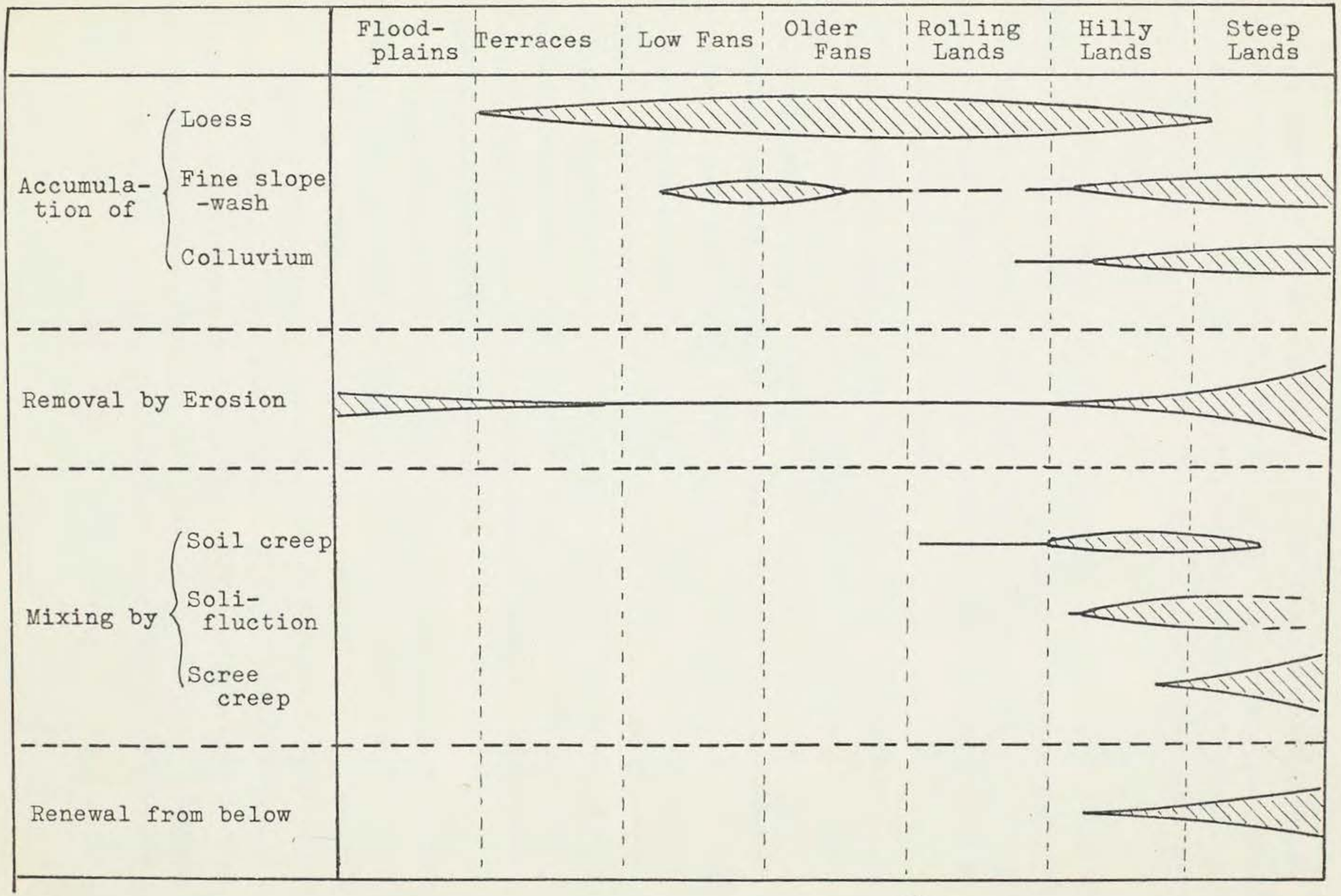


Figure 28

In areas of lesser stability, the action of gravity inconjunction with factors of topography (slope) and vegetation (Density and Pattern) have resulted in the destruction and distortion of the simple morphological succession one would expect in an alto- or topo- sequence.

On moderately to strongly sloping sites, slow soil creep had effected the introduction of coarser fragments into the lower solum of soils derived essentially from loess. With increasing altitude and slope such movements result in gravels and stones forming an increasing proportion of the solum.

Solifluction appears to have operated in an earlier cycle on some sites of cooler, moister and more sheltered aspect at lower levels (Plate 21), but such sites now appear to be more stable and unaffected by such effects. At higher altitudes, where freeze and thaw cycles are common during winter, it is probable that mixing as a result of solifluction is still occurring. However, definite evidence of such was not observed and so must be inferred from climatic conditions. Scree creep is an active phenomena, particularly among the soils of steep slopes largely derived from slope debris deposits. The "loamy screes" found in such areas are definite evidence of this phenomena.

Colluviation tends to reduce the obvious morphological aspects of soil formation and is responsible for the incorporation of both relatively unweathered and more strongly weathered material into all levels of the solum. These effects of creep and solifluction are less severe on those soils developed from mixed loess and colluvium as evidenced by the minimal disturbance shown by the buried part-profiles observed in these soils. This is probably a reflection of the greater stability afforded by the vegetative cover of such zones. However, this simple relationship must be interpreted in the light of the greater concentration of burning and grazing activities in European times on drier more exposed sites, where vegetation is more sparse and soils are derived from colluvium with little or no loessial influence.

(c) <u>The role of erosion in soil formation</u> - While material is being accumulated either by airborne accretion or is moved down-slope under the influence of gravity, it is subjected to the erosive influences of water and wind. In such situations it is difficult to assess the extent to which "normal erosion" is affecting the soils of the area. The effects of more severe erosion, however, are particularly obvious on the coarse textured high angle fans and steeper hillsides. On the rolling loess covered downlands, evidence of other than normal erosion (see Plate 9) is usually absent, and it may be inferred that soils on such terrain are only subjected to the normal regressive effects of erosion.

Accelerated erosion has in the past been particularly marked on soils developed from colluvium, but on soils from mixed loess and colluvial materials it has operated to a lesser degree. The apparent stabilisation and revegetation of some coarse screes (of probably pre-European age) indicates that erosion has not been as active in recent times as in the immediate past.

Gully-head, stream bank (Plates 20, 6, 7) and stream bed erosion is still a feature of the gorge and upper basin regions, indicating re-establishment to a new grade as a result of changes in base level. Wind erosion of fines from terrace and fan surfaces and the washing of fines from low ridges on these surfaces into adjacent hollows is common. Fine loess-like material is commonly blown off the younger fan surfaces and from the Mowbray river bed

PLATE 19. Evidence indicating at least 4" of accumulation of windblown and possibly rewashed fines on the 'rewashed loess' surface (Wakanui series) in relatively recent times.

PLATE 20. Upper basin of the Mowbray. Fiery Top on the left and Lookout Peak on the right. Recent gully-head erosion is cutting into an old surface on the forward slope of Fiery Top.

PLATE 21. Solifluction terracettes - Kakahu hill soil.

during nor'west winds indicating that erosion of soils in these locations is still actively proceeding.

Thus the effect of erosion in the Mowbray catchment is one of both regression and accumulation. Gains are particularly apparent on rolling surfaces where slope-wash from moderately sloping hillsides accumulates on adjacent gently sloping surfaces in footslope locations, producing greater apparent depths of sola.

(d) The incorporation of material from below the solum - Stripping of material from the surface causes the agencies of weathering to penetrate deeper into the underlying C, D or buried horizons thus leading to the incorporation of new material into the solum. Deep mixing of soils due to creep and/or solifluction may also introduce new material into the solum. The addition of this material can affect the weathering stage of the soil in three ways:

i. on alluvial sites, and soils developing on greywacke rock proper, fresh unweathered or only weakly weathered minerals and rocks are incorporated into the solum following erosion of parts of the surface horizons. In such cases the stage of weathering decreases down the profile;

ii. on steep hillsides where soils are developed over deep deposits of colluvium, new material introduced into the lower solum as a result of mixing and erosion is at a stage of weathering similar to that of the solum. As a result such soils display uniform weathering throughout;

iii. soils derived from loess of from mixed loess and colluvium overlying an older loess or buried part-profile tend to display more advanced stages of weathering in the lower solum. This is because of the more advanced stages of weathering of these underlying pedogenic materials, which may be introduced into these lower horizons as a result of surface erosion or deep mixing.

(2) The Influence of the Later Quarternary History

Fundamental to the cyclic development of the soils of the Mowbray catchment have been the events occurring since the end of the last advance of the Otiran glaciation, about 14,000 years ago. In Chapter IV, section 5, an attempt has been made to relate the events occurring elsewhere in Canterbury to sedimentation and erosion in the Mowbray catchment. It is not proposed to reiterate here the discussion of that section. It is evident, however, that the change(s) in climate, fluctuations in base level and variations in the nature and extent of vegetation, in post-glacial times, have had a marked effect on the formation of these soils.

Erosion following the removal of permanent and seasonal snow at the end of Otiran times resulted in the formation of the older alluvial soils and initiated deposition of loess and probably mixed loess and colluvial materials on older loess or rock waste. Only the Kirkliston series remains to show the nature of the previous regolith. Subsequent to this early post-Otiran period of sedimentation, three periods of erosion and deposition have modified or completely removed these early soils. Sites on which loess tended to accumulate during periods when the vegetation cover was reduced have been stable over most of this time. On steeper sites, newly formed soils were completely or partially removed and mixing with more loess and/or colluvial debris resulted. During such periods of erosion a series of fans and terraces were built up in the valleys and lower basin.

These erosive periods, following the removal of the covering vegetation by natural fires, have been correlated with events elsewhere in the Canterbury area. It is only the destructive influence of man's arrival in New Zealand, however, which can be correlated with any certainty. The effects of accelerated erosion seen as poorly vegetated coarse screes and loamy screes and as gully-head erosion are due to European interference. The more stable soils on the hilly and steep lands have probably existed in their present form for a much longer period and pre-date the arrival of Polynesians.

(3) The Interaction of the Factors of Soil Formation

Soils are dynamic entities which result from the interaction of a number of factors. It is only when a situation exists wherein all of the factors of soil formation but one remain constant in a sequence of soils that the effects of that factor (Jenny 1941) can be assessed. In this case, the influences of the drift regime and the importance of events in the post-glacial period have been emphasised, but an appreciation of the overall interaction of all features influencing the formation of these soils is necessary in order to understand their genesis. Other factors influencing these soils have been outlined in preceeding sections. It only remains to discuss the soils of the whole of the Mowbray catchment in terms of these factors and show how these factors influence each other.

(a) Topography, vegetation and climate - The influence of topography manifests itself in several ways. The high level of the water table in the sites occupied by the Taitapu and Wakanui series has been responsible for the mottling and gley features exhibited by these soils. Perching of the water table in soils derived from loess has induced incipient gley features in many profiles, particularly those of the Skipton series (see Appendix 1). Those series in the lowest lying locations show the greatest effect (e.g. Clayton). Profiles on sheltered aspects (or minimal exposure) show the effects of longer, moister periods than those soils on more exposed aspects. Coupled with these features are the positions of the profiles within the soil landscape. Those soils in down-slope, accumulative sites show paler colours and more pronounced mottling (e.g. Opuha and Skipton series).

The slope and shape of a hillside influences not only the moisture regime of the soil but coupled with aspect can influence the extent and amount of accumulation of loess and slope-wash materials. Similarly, a combination of slope, aspect, the moisture regime (incorporating temperature fluctuations) and the thickness of accumulated loess can influence the activity of the mixing cycle.

On the strongly sloping and steep hillsides, aspect, slope and the moisture regime become particularly significant, more particularly when considered in the light of the nature and extent of the vegetative cover. The erosive effects of the drift regime are more pronounced on areas of restricted cover. Mixing of material takes place to a greater depth in the solum and the chances of inclusion of material from below are enhanced.

The accumulation of windborne material is dependent not only on a source of material, and a site of deposition, but also on the strength, direction and persistence of the prevailing winds. The deepest soil development is found on northwest facing slopes where loess, brought by the prevailing nor'wester, tends to accumulate. On slopes of southeast to southerly aspects, on hilly and steep lands, deep soils are also encountered. These are soils developed from mixed loess and colluvium (e.g. Puketeraki and Lookout series) and they owe their depth to a combination of inherently greater stability, and better moisture regime, relative to soils derived from colluvial deposits on adjacent slopes, and the accumulation of fines transported by winds associated with southerly storms. The better vegetative cover on southerly aspects in this zone serves as a trap for wind-blown material.

The contrast in sub-soil colours between less exposed and more exposed aspects on hilly and steep lands can be attributed to greater levels of moisture on the former aspects and the more pronounced effects of mixing on the latter sites. In the moister soils iron compounds are reduced and in this stage impart paler colours to the lower solum. On the more exposed sites, the more rapid drying of these soils results in the oxidation and reprecipitation of the solubilised iron compounds in the solum proper, thus resulting in coloration of a redder hue. In addition, fresher material introduced from below the solum by more active colluviation in these latter sites, on the initiation of weathering, affords a new supply of amorphous iron compounds. Similarly, on rolling and gently sloping surfaces those soils with better drainage tend to exhibit stronger subsoil coloration of redder hues. It can be seen then, that the physical nature of the parent material itself influences the morphology of the soils on all sites. The nature of the parent material depending to a great extent on the operation of the processes of the drift regime and the accumulation of alluvial deposits.

(b) <u>The drift regime and soil formation</u> - Thus, it is apparent that the effects of the environment and soil formation are interdependent. The soils reveal the effects of the influences of the drift regime. The processes of the drift regime are influenced by the effects of the various factors of soil formation - time, topography, vegetation, climate. The influence exerted by these factors on the soils is dependent upon the nature of the parent material, which is itself, a product of the processes of the drift regime.

In order to determine the extent and direction of soil formation on the various surfaces it is necessary to interpret observations in the light of modifications imposed by the drift regime. An examination of the most stable site within each topographic zone will result in predictions pertinent to the extent and degree of modifications imposed by the drift regime and by the factors of soil formation. With this consideration in mind the following generalisations relative to soil formation may be made about the chemical and mineralogical characteristics of the soils of the Mowbray catchment:

(i) soils on hilly and steep lands which are more actively colluviated are less leached and have greater reserves of P than those soils on less actively colluviated sites;

(ii) of the soils derived from loess those in the drier more exposed aspects tend to be more weathered and leached than those soils in the moister, cooler, more sheltered aspects;

(iii) of the soils derived from loess with evidence of mixing in the lower solum, the degree of enleaching increases and P reserves decrease with increasing precipitation;

(iv) the degree of weathering in soils derived from any one parent material increases with increasing precipitation; those stable soils on ridge crests at high levels being more weathered than soils derived from loess, which in turn are more weathered than soils displaying evidence of colluviation (particularly in the lower solum).

Thus it can be seen that the influences of the active processes of the drift regime coupled with those of the static factor topography (aspect, moisture and exposure) have exerted the greatest

<u>influence on the formation of the soils of the Mowbray catchment</u>. The influences due to time, vegetation and the nature of the parent material tend to complement the irregular pattern of development created by the influences of the drift regime and topography. The overall effect of the climate, on the other hand, is tending to induce some measure of order into the sequences of soil formation in the catchment.

(4) LAYERING OF LOESS

During the detailed field examination of the soils of the Mowbray catchment it became apparent that the compact (loess) "hard-pan" forming the C horizon in soils derived from loess was of different genetic history to the overlying loessial materials:

(i) the pan has a distinctly stronger colour than the B horizon, i.e. value and chromas remain the same but pan is invariably one hue redder than the B horizon (e.g. 2.5Y/10YR or 5Y/2.5Y);

(ii) in many cases a distinct textural difference was noticeable, the pan having a <u>lighter texture</u> than the overlying B horizon;

(iii) an obvious drainage impediment was correlated in the field with the presence of discrete mottles and sometimes small iron concretions in the horizon above the pan. This feature was particularly marked in pits examined after rain, and varied from 2" to 6" in thickness.

Although the pan appeared to be in the position of a C horizon, and the lighter texture suggested greater weathering in the solum above, chemical and mineralogical examination of samples revealed that in fact, the pan was more weathered and leached than the solum. One was consequently forced to the conclusion that the pan represented a remnant of a former soil which had been largely removed during a previous erosive phase. The current soil resulting from the sbusequent accumulation of loess-like material.

If the pan had existed as such in a previous soil, it is logical to assume that due to its compact nature, it would be able to resist erosion to a greater extent than the earlier more friable solum. Raeside (1964) suggested that the compaction of loess-like sediments, during glacial advances was due to wetting and drying cycles in a cool, dry environment. Comparable conditions probably existed in the Mowbray during the last advance of the Otiran glaciation. Thus, the remnant pan probably corresponds to Raeside's loess No. 1 (1964). The soils of the Meikleburn and Sherwood series on the alluvial fans are derived from the upper part of this early loess deposit which was extensively eroded at the end of the last ice advance. Subsequent accumulasion of loess of more recent origin has given rise to the present soils. Additional weathering, and the softening of the upper part of the remnant pan no doubt occurred, but the initial, fairly rapid accumulation of more recent aeolian sediments, protected the remnant pan to a large extent from such processes.

A more logical explanation would assume that the pan represents an even earlier loess layer. Probably loess No. 2 of Raeside (1964) and the more recent overlying layer corresponding to Raeside's loess No. 1. If this is the case, it is necessary to explain why there is no evidence of compaction and panning in the younger loess, since such a process was considered to be a feature of the deposition of loess in cold, dry stadial times. Also, the deposition of loess in post-Otiran times over extensive areas of the Canterbury Plains and in parts of Otago would indicate that an environment existed at this time during which extensive loess accumulation could occur. (Leamy 1969 suggests a maximum age of

3,500 years for a recent loess deposit, with a pan, in the Manuherikia Valley).

If the major part of the solum of the soils overlying a compact loess-pan is of more recent origin than the formation of the pan, it is probable that corresponding older horizons exist in other soils with essentially loess-derived sola. An examination of the chemistry and mineralogy of those soils on rolling and hilly surfaces which are derived from loess over mixed loess and colluvial materials also indicates a greater degree of weathering and leaching in the lower mixed horizons than in the horizons above.

Figures 21, 22 and 23 show pertinent chemical and mineralogical data which it is considered indicate layers in soils derived from loess. Data from the Opuha, Tengawai hill and Kakahu series derived from loess, and the Tekoa and Puketeraki steepland soils derived from colluvium, and mixed loess and colluvium respectively are presented. Trends shown by these soils are typical of the respective groups and the following observations concerning the BC and underlying horizons relative to the upper parts of the solum may be made:

(i) Soils derived from loess over an underlying loess or mixed loess and colluvium layer show an increase in Pf relative to Pa in the BC and underlying horizons. This is indicated by the shape of the Pa/Pinorg curve (Figure 21) and the absolute amounts of the fractions present. Differences in the Pa/Pf ratio between horizons in the one soil may be due in part, to differences in the proportions of physical size fractions (as noted above), but it is considered that these differences in Pa and Pf between B and C or D horizons in the one soil are so marked that they must also indicate differences in intensity of weathering and leaching between these horizons. By contrast, soils from essentially colluvial materials have a reduced Pf/Pa ratio in the BC and C horizons and have lesser amounts of Pf in these horizons than in those above.

(ii) Soils derived from essentially colluvial materials have at least equal levels of exchangeable potassium (expressed as m.e.q./100gm) in the B horizon and in underlying horizons. Loess derived soils on the other hand have lower levels of exchangeable K^+ in the BC and lower horizons than in the B horizon.

(iii) It is considered that the ratio, "exchangeable $\frac{Ca + Mg}{K}$ ", gives a more accurate picture of the state of leaching and weathering of the soils, especially when considered in relation to exchangeable potassium levels. This ratio is based on the premise that weathering and leaching of primary (and certain secondary) minerals releases and removes Ca, Mg and K ions. Ca and Mg ions are released by weathering more rapidly than K ions because of the greater susceptibility of Ca and Mg containing minerals to weather (Barshad 1964). Thus initially as Ca and Mg are removed the $\frac{Ca + Mg}{K}$ ratio would become smaller. Progressive weathering and leaching would bring about a subsequent increase in the ratio. In fresh material, however, the ratio could also be quite high so interpretation must take into account the levels of exchangeable potassium. Thus the curves of this ratio for the Opuha and Kakahu series show a dramatic rise below the subsoil. Those soils from essentially colluvial materials, on the other hand, show only a slight rise in the ratio in similar horizons. a feature which would be expected in the presence of fresh material. The dramatic increase in this ratio seen in the deeper subsoil of profiles from loess and the very low levels of potassium in such regions is considered to indicate the greater degrees of weathering and leaching experienced by these layers.

(iv) The basic direction of weathering of micaceous minerals in zonal soils is from micas $\longrightarrow$ illite $\longrightarrow$ vermiculite (Fieldes and Swindale 1954, Fieldes and Taylor 1961, Fieldes 1962 and Soil Bureau Staff 1968b). A comparison of the relative proportions of 10 Å and 2:1 14 Å minerals at various levels in the profile would be indicative of the relative degree of weathering in various horizons. Figure 23 reveals that soils derived essentially from colluvium or greywacke rock in place have greater amounts of illite and lesser amounts of clay-vermiculite in their BC and C horizons than in their upper sola. Such features indicate progressive weathering from the surface downwards. Soils derived from loess may in some cases show an increase in illite and a decrease in vermiculite with increasing depth. Faulkner (1968) also noted such a trend in the loess derived solum of two dry-hygrous yellow grey earths from North Canterbury; the upper loess giving rise to the present soils was considered to have deposited in post-glacial times on early Otiran outwash fan gravels capped by a loess deposit of early or mid-Otiran age. However, in the BC horizons and underlying layers reduced amounts of illite and greater amounts of clay-vermiculite are evident, indicating a greater degree of weathering in these layers than in the lower solum.

The evidence presented, based on morphological, chemical and mineralogical contrasts has led to the proposal of a theory of layering of material in the majority of the soils derived from loess. As a result observations and discussions on the genesis of the current profiles of the soils of the Mowbray have been confined to the development of the solum above such compact layers of loess or mixed loess and colluvium. The sola in most cases are derived almost exclusively from loess of recent deposition. The nature of this loess is conditioned by the extent to which eroded material from older surfaces has contributed to its make-up.

Acceptance of such ideas of layering of loessial material, even in recent times, leads to some significant observations in the Mowbray catchment:

i. the development of a fragipan, hard-pan or loess-pan in loess derived soils is a feature of a previous weathering cycle and is not a feature of pedogenesis during the present period;

ii. accumulation of loess is a feature of inter-stadial glacial periods;

iii. accumulation of loess may even be occurring today on some moderately to strongly sloping hillsides and is almost certainly a feature of many less strongly sloping surfaces;

iv. on rolling and hilly lands it is possible to correlate depositions of loess with the formation of deposits of material indicative of reduced stability;

v. it may even be possible to extend such correlation to include buried (or resurrected) soils on surfaces in steep lands;

vi. detailed examination of previously acquired chemical and mineralogical data may turn up evidence indicating the widespread occurrence of this phenomena in the South Island generally.

(5) THICKNESS OF SOIL DEVELOPMENT

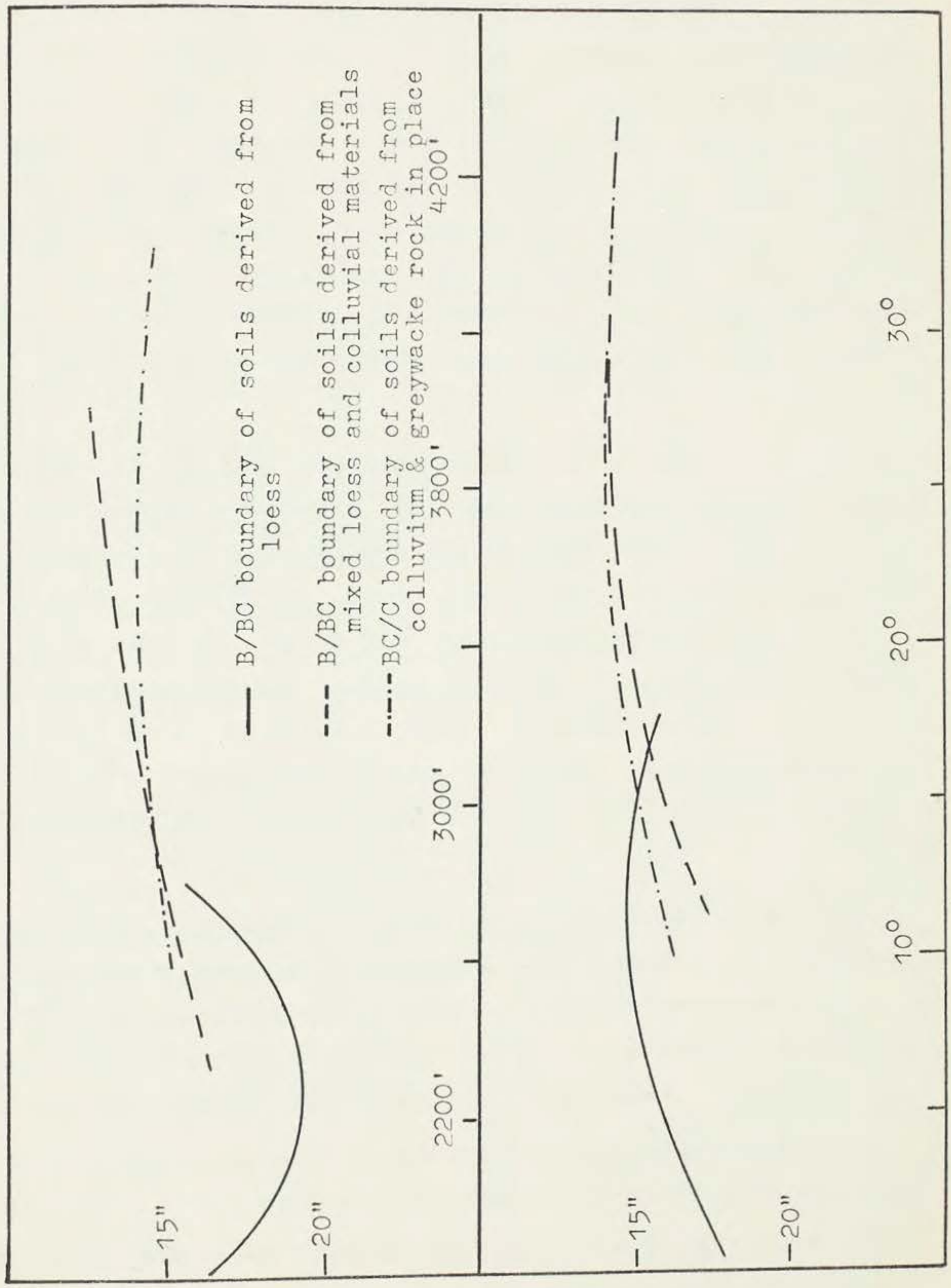
The depth to which a soil develops is the result of the relationship between the climate, the physical and chemical nature of the parent material and the degree of stability of the parent material and developing soil. In the case of the soils derived from loess, many profiles reveal that all of the post-glacial loess forms part of the solum and the current weathering processes are starting to affect the upper part of the underlying older material. In other profiles, however, current weathering has had only a minor effect on the sub-sola material and then probably only during its deposition.

Appreciation of these observations tends to the conclusion that the BC horizon is not a reliable indicator of the depth to which weathering is currently occurring. Rather, for such loess derived soils the base of the B horizon is probably more indicative of the true thickness of profile development in the present cycle. The inclusion of parts of buried profiles into the lower solum of soils derived from mixed loess and colluvium as a result of mixing has also led to a consideration of the base of the B horizon as the maximum depth of profile development in such profiles. On the other hand, soils developed from predominantly colluvial materials (and on greywacke rock in place) have the effects of current soil development apparent throughout the whole of their sola. As a consequence the depths to which soil development has occurred are represented by the thickness of the sola.

On this basis, a comparison was made of the depths to which the profiles from various parent materials were developed (Figure 29). The thickness of development of soils from mixed loess and colluvium and from colluvium was found to be comparable over a wide range of altitude and slope. Soils derived from loess form a natural thickness sequence with soils derived from mixed loess

FIGURE 29

COMPARISON OF DEPTHS TO BASE OF PROFILE OF SOILS FROM DIFFERENT PARENT MATERIALS RELATIVE TO SLOPE AND ALTITUDE



and colluvium and soils from essentially colluvial materials, and show progressive increase in thickness with decreasing slope. Since the soils of these three classes are representative of a balance between accumulation and regression within their respective parent material zones, the curves in Figure 29 indicate that accumulation is at a maximum in regions of least slope within each zone. Soils derived from loess show a thickening of the profile on slopes greater than 14^{o}. This may be attributed to accumulation in some sites, and a greater depth of weathering encouraged by more friable subsoils where mixing with underlying mixed loess and colluvial materials has occurred in the lower solum (e.g. Kakahu hill soils).

Changes in the thickness of the soils of these three parent material zones with increasing altitude reveal the combined effects of both thickness of accumulation and depth of weathering:

(i) Soils derived from loess attain their maximum thickness at 2200 ft to 2400 ft. Above 2500 ft regression probably keeps pace with accumulation and despite increases in precipitation with increasing altitude, the high exposure of sites at this level means that the effectiveness of the increased precipitation in relation to depth of weathering is reduced (e.g. Tengawai hill soils).

(ii) Soils developed in mixed loess and colluvial materials show a progressive decline in thickness with increasing altitude. This may be attributed to regression exceeding accumulation with increasing elevation and as the watershed is approached, a decline in the supply of waste forming the parent material.

(iii) Soils developed in colluvium show similar trends to those outlined in (ii) with the exception that above 4000 ft soils developed over greywacke rock in place on ridge crests show a greater depth of weathering and soil development than adjacent soils on steep hillsides at slightly lower elevation.

Comparisons such as this indicate the significance of the combined effects of the interaction of all the processes and factors of soil formation. A more active drift regime on some sites produces a depth of development equal to that produced by moister but cooler conditions on more stable sites, which in turn may be equated with similar depth of development on sites of warmer but drier conditions where finer parent materials occur.

Once a medial curve of soil thickness for a range of soils has been constructed (Figure 29), it is possible to make estimates of the relative degree of stability of soils within the class examined. The medial curve is assumed to indicate normal conditions of formation for the soils of that class and deviations from the medial can be interpreted in terms of the soil forming processes as influenced by the factors of soil formation. An extension of such a study is the assessment of the degree of stability of certain soils and interpretations may be made as to the extent to which other than normal erosion has affected such soils in the immediate past.

It may also be concluded that similarity in depth to the B/BC boundary in profiles derived from loess and mixed loess and colluvial materials and the BC/C boundary in soils developed in colluvium indicates that the BC horizons of the two former classes are probably part of a former weathering cycle.

CHAPTER IX

CONCLUSIONS

The main purpose of this study was the detailed survey and mapping of the soils of the Mowbray catchment. Prior information, relative to the anticipated soil pattern was available at only the broadest of scales. Little detailed information was available on the way in which the processes of soil formation affect the morphogenesis of soil sequences in upland and high country basins such as that encompassed by the survey. Some detailed studies had, however, investigated the effects of the soil forming factors and processes on both similar and unrelated soils and it was possible, where applicable, to extrapolate from such information to the events and processes affecting soil formation in the Mowbray catchment.

Because of the wide spectrum of this investigation, many aspects of pedology, ranging from survey and ampping through classification and environmental reconstruction, to morphological, chemical and mineralogical genesis were discussed. In order to present a logical conclusion points will be enumerated according to these various aspects of pedology. Such is the complex nature of pedology, however, that many of the points made below may be equally applicable as a concluding remark of sections other than the one in which they are grouped for presentation herein.

1. Survey, Mapping and Correlation of Map Units

(a) In the past, the broad mapping of the upland and high country areas for the production of small scale maps, has relied heavily on vegetation/terrain/climatic contrasts for the identification and separation of map units (series or sets) rather than intensive profile examination.

(b) To meet the demands for increasing information concerning the nature and distribution of soils in upland and high country areas, more intensive profile and landscape examinations are required. However, in the production of soil maps of large scale, it has been shown that rapid techniques of aerial photographic interpretation and field binocular observation can replace to a large extent the "following of boundaries" in the field.

(c) Air photos are particularly useful since:

i. they can be used to separate soils at the series level in both downland and steepland environments;

ii. in steepland regions soils can be delimited on the basis of terrain, vegetation, surface stoniness and moisture contrasts - similar features to those used to identify soil units on more extensive surveys;

iii. they are, however, limited by the complex nature of sedimentation on fans and terraces and generally are only capable of showing relative age differences amongst such surfaces.

(d) Such interpretation should not necessarily be confined to vertical air photos. Low and high angle oblique aerial photographs can also be of use, particularly where ground control has been established.

(e) However, photo-interpretation alone is not sufficient to enable complete determination of the inter-relationships and patterns of upland and high country soils. Detailed traverses and/or strip mapping are a necessary complement to any form of interpretation which does not require extensive field investigation.

(f) Because of a paucity of precise environmental and morphological data pertaining to many of the soil sets established during the South Island survey (Soil Bureau Staff 1968a), the correlation of soils determined during this detailed survey, with existing sets/series, has proved difficult. Such difficulties will continue with future detailed surveys and can only be surmounted by an intensive investigation of all previous information related to the soils of upland and high country areas and the formulation of moderately rigidly defined limits for soil sets and soil series. Bearing in mind the probable future use of computers for the storage of data and for correlation purposes, it is essential that the maximum detail be recorded about each site and profile examined. Wells and Jackson (1969) have indicated a minimum number of 42 separate observations per horizon (or in some cases a minimum of 71 observations per soil profile) as the requirement for effective computerisation of profile information. This means that in the future the soil surveyor will need to record site and profile information in a prescribed format similar to that shown as Appendix 4 which is based on Leamy and Panton (1966 p. 130).

(g) Information is currently available on the pattern of soils in upland and high country regions of the South Island at a scale of four miles to one inch. In order that planned use of the soil resource may be made, in such areas, on both a regional and county basis, soil maps at a larger scale must be produced. This study has shown that it is possible to produce maps in the high country at a scale of 20 chains to one inch. The practicality of maps at such a scale is, however, doubtful. Resource planning in the future in the upland and high country areas must take into account:

i. water resources;
ii. conservation requirements;
iii. recommendations and conclusions pertaining to extensive pastoralism;

iv. continued indigenous or establishment of exotic protection forestry;

v. recreational resources;

- and considering the aspects of availability of manpower, accessibility of areas to be investigated and the availability of aids to survey (i.e. air photos at scales of 50 chains to one inch and one mile to one inch), it would appear that map production at a scale of one inch to one mile (or 1:50,000 in the light of current mapping being undertaken in selected areas by the Department of Lands and Survey), would best fulfill the needs of the information required. In areas where there is an apparent potential for intensive pastoralism, cropping or specialised horticulture, mapping should be carried out separately at a scale of 40 chains to one inch (or 1:25,000).

(h) This study has revealed:

(i) that due to the complex pattern of soils in many locations the soil type is too fine a mapping unit to be employed on such surveys in upland and high country areas;

(ii) that the soil series of the soils derived from loess have almost identical profile development over a wide terrain range and it becomes questionable whether it is necessary to distinguish "hill phases" of such soils as separate mapping units;

(iii) that associations and complexes must be accepted mapping units even on detailed soil maps of upland and high country areas unless -

(iv) there is a reappraisal of the extent (and amount) to which inclusions within homogeneous mapping units may be tolerated without the need to establish heterogeneous units.

2. <u>Relationships Betwenn Late Quarternary Events and Landscape Genesis</u>

(a) An attempt has been made to correlate events leading to the formation of post-glacial soil surfaces on the Canterbury Plains with the probable sequence of events in the genesis of the landscapes of the Mowbray catchment. A more intensive investigation could reveal sufficient deposits of charcoal to enable chronological correlation on the basis of C^{14} dating. However, at this stage, the tentative correlations established do seem logical and it should be possible, on future surveys, to extend this correlation to other high country areas.

(b) The accumulation of loess on rolling country can be correlated with the formation of mixed loess and colluvial deposits on steeper slopes.

(c) In areas where deeper deposits of loess or mixed loess and colluvial materials are absent it can be inferred that such areas have been subjected to periods of instability in the post-glacial period.

(d) Instability which has occurred on steep slopes at higher altitudes has provided the bulk of the waste which has been responsible for the periodic sedimentation leading to the formation of fans and terraces in the lower basin. Leamy (1969b) has shown how, by simple calculations, the amount and extent of the regression on steeper slopes at higher altitudes, may be assessed.

(e) The periodic instability which has affected such areas can be related to changes in form and distribution of vegetation. The present pattern of vegetation indicates both areas of stability and instability and as such can serve as a guide in the identification and delimitation of soils.

3. <u>Assessment of Stability of Soils and Regolith</u>

(a) Soils developed from loess, or where loess has played a role in the formation of soils on steeper slopes, have the greatest stability.

(b) It appears that where loess has accumulated to sufficient depth to prevent the erosive effects of needle ice and related freeze and thaw cycles disrupting the solum by effecting the concentration of coarser fragments in the upper profile, a continuous vegetation cover has established and stability has resulted.

(c) The hill phases of some soils developed in loess, over either an older loess or mixed loess and colluvium, commonly show more advanced stages of morphological development than related soils on undulating and rolling terrain. It is logical to suppose that the more weathered (and developed) soils within this class will be those which are also the least eroded. Consequently, it is evident that soils derived from loess have a high degree of inherent stability which persists over a variety of terrain types ranging up to those with slopes of 20°.

(d) It may also be concluded, that despite the inference of periodic instability, the norm for the soils on steep slopes is one of a moderate degree of stability with the potential for instability under certain circumstances.

(e) On the basis of (d) it is possible to construct average soil thickness/altitude/slope - curves for various soil classes or terrain units and so conclude as to the current state of regression or accumulation of particular sites and/or map units.

4. Soil Genesis and Variability of Morphological, Chemical and Mineralogical Characteristics

(a) One of the main identifying characteristics of the yellow grey earths, yellow-grey to yellow-brown earths intergrade and related shallow and stony soils is the occurrence of a pan within the solum or C horizon. These are pans of compaction in the former two groups and of cementation in the latter group and are generally considered to be a feature of current soil formation within the respected environments. A fragipan has been observed in the profiles of soils derived from loess but is has invariably been associated with either the underlying older loess or mixed loess and colluvium; in which situation it is considered to be a product of a former cycle of soil formation. Similarly, where a cemented pan (probably due to finely dispersed hydroxy-iron compounds) has been observed in the shallow and stony soils on the terraces and fans, it is invariably associated with part of a buried solum. Consquently one is forced to conclude that either:

(i) neither type of pan formation is currently occurring as the present environment is not conducive to pan formation; or

(ii) the more recent deposits of loess are not sufficiently thick to allow effective pan formation to occur; and

(iii) in the case of both types of pans, soil formation has not been operative over a sufficient length of time to produce the conditions required for pan formation.

(b) In Chapter VIII the importance of the effects of the drift regime have been discussed in some detail but no mention has been made of the process of flushing. In the Mowbray catchment there is a lack of definite morphological evidence indicating that this process has occurred. Flushing is considered to be a common process affecting the formation of high country soils and it is not unreasonable to suppose that it does occur in soils on the steeper slopes within the catchment. However, the lack of evidence for this process would tend to indicate that the precipitation experienced in the Mowbray is minimal for the effective operation of the process and as such, it has had only a very minor effect on the soils of the region.

(c) The complex relationships between the morphological assessment of development, and the various phosphorus fractions in

FIGURE 30 PROBABLE SEQUENCE OF WEATHERING OF SILICATE MINERALS IN THE SOILS OF THE MOWBRAY CATCHMENT

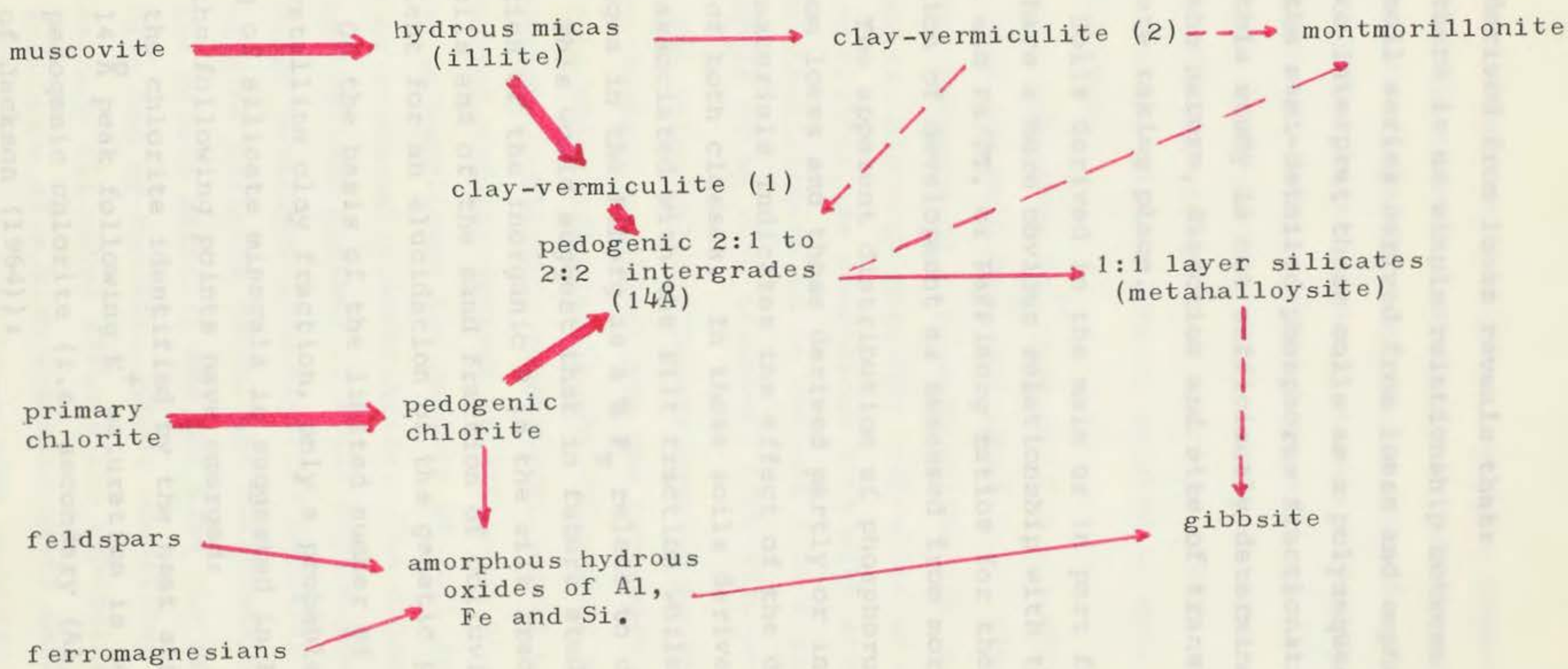


FIGURE 30

the soils derived from loess reveals that:

(i) there is no simple relationship between the individual soil series derived from loess and emphasises the need to interpret these soils as a polysequence; and

(ii) the semi-detailed phosphorus fractionation as used in this study is not sufficiently determinative to reveal the nature, direction and site of transformations which are taking place.

(d) Soils derived in the main or in part from colluvial materials have a more obvious relationship with the P fractions as determined and Pa/PT, or Pa/Pinorg ratios for these soils reflect the direction of development as assessed from morphology.

(e) The apparent distribution of phosphorus within the soils derived from loess and those derived partly or in the main from colluvial materials indicates the effect of the drift regime in the formation of both classes. In those soils derived from loess Pinorg is associated with the silt fraction while in the latter class changes in the Pinorg as a % P_T relate to changes in the sand fraction. This would suggest that in future studies, a detailed fractionation of the inorganic P in the silt fraction of loess derived soils and of the sand fraction of colluviated soils could be sufficient for an elucidation of the genetic picture.

(f) On the basis of the limited number of observations made on the crystalline clay fraction, only a probable sequence of weathering of silicate minerals is suggested in Figure 30. In addition the following points have emerged:

(i) the chlorite identified by the heat stability of the 14 Å peak following K^+ saturation is considered to be pedogenic chlorite (i.e. secondary (Al, Fe, Mg) chlorite of Jackson (1964));

(ii) gibbsite is being rapidly formed during the weathering of feldspars and ferromagnesian minerals in this environment - this transformation probably passes rapidly through a stage during which amorphous hydrous oxides of Fe, Al, and Si are formed. The occurrence of gibbsite is commonly associated with decomposing greywacke stones within the soil profile;

(iii) both forms of clay-vermiculite as determined according to Fieldes (1968) and Claridge (1969) have been identified, and they can be related to soil conditions as follows:

low exch Ca^{2+} and $pH > 5.5 \longrightarrow$ clay-vermiculite (2)

very low exch Ca^{2+} and $pH < 5.5 \longrightarrow$ clay-vermiculite (1)

(iv) the presence of clay-vermiculite (2) in strongly acid soils, although possible indicative of changing soil conditions, is considered both with metahalloysite and montmorillonite to be derived from a previous weathering cycle or by wind transport from adjacent regions.

(g) The principal influences exerted on the formation of the soils of the Mowbray catchment are the processes of the Drift Regime. Subordinate to these effects are the influences exerted by the factor topography. Climate, vegetation, parent material and time have all exerted varying degrees of influence at different sites, thus tending to complicate the pattern of soil formation within any soil group or topographic association. The major influences affecting the various classes of soils may be summarised:

(i) Soils developed from alluvial deposits under conditions of free drainage reveal the influence of the texture of the parent material and the time the effects of climate have had to operate. Under conditions of impeded drainage all other effects are subordinate to the influence of a high standing water table.

(ii) Soils derived from loess have resulted in the main from the effect of the drift regime, as manifested in the transportation and accumulation of loessial deposits. Aspect, site exposure and the level of the ground water are all influences due to topography which have tended to confound any simple sequence which may have been induced by a uniform blanket of loess.

(iii) Soils either partially or wholly derived from colluvium have been affected to the greatest extent by the various processes (mixing, removal and accumulation, and renewal from below) of the drift regime. Variations in topography and vegetation tend to enhance differences created by variations in the intensity of the different processes of the drift regime.

(g) In addition, variations in the time during which the soil forming processes have been operative, variations and changes in the nature, distribution and completeness of vegetative and wide differences in the chemistry, mineralogy and texture of the parent material have tended to complicate the soils pattern and genetic picture. The influence of climate over the whole catchment is such that it is possible to divide the region into three main soil zones:

(i) zone of yellow-grey earth formation where the soils may experience five months or more when soil moisture is below field capacity and where the rainfall ranges from 28" to 32" annually;

(ii) zone of upland and high country yellow-brown earth formation where the soils are rarely below field capacity in any one month, although short periods below field capacity may be experienced - rainfall exceeds 35" annually;

(iii) zone of formation of yellow-grey earth to yellow-brown earths intergrade where the soils may be below field capacity for up to five months annually but usually for only three months or less - annual rainfall range 30-35".

	gammate	sub-gammate	weakly sub-gammate	weakly weathered	moderately weathered	strongly weathered
weakly leached						
				TEKOA		
moderately leached	SKIPTON	CLAYTON		CLAYTON	SKIPTON	
		KAKAHU	OPUHA	OPUHA – KAKAHU		
strongly leached				LOOKOUT		
			TENGAWAI		TENGAWAI–KAIKOURA	
very strongly leached		SHERWOOD			PUKETERAKI SHERWOOD	KIRKLISTON
	YGE and YG-YBE Intergrades			YGE, YG-YBE Intergrades and Upland and High Country YBE		

TABLE 16 Genetic Relationship of Soils on Older Fans, Rolling, Hilly and Steep Lands

(h) Soils developed over alluvium show a progressive increase in development with increasing age:

Tasman → Ashwick → Mowbray → Meikleburn

(poor drainage) (imperfect drainage)

Taitapu Wakanui

The development of those soils on the older fans, rolling and steep hillsides is summarised in Table 16.

5. <u>Classification</u>

(a) The soils of the Mowbray catchment have been classified according to the three major systems of classification which have been used in New Zealand since the late 1940s. The advantages and disadvantages of each system have been discussed in Chapter VI and the relationship between them is illustrated in Table 17, wherein the soils of the catchment are classified according to each system.

(b) The soils of the Mowbray catchment can, in general, be classified on morphological and environmental bases according to the common genetic classification. Some disparity does exist when considering the positioning of the shallow and stony soils on the terraces and low angle fans. In particular, the Ashwick and Mowbray series, which no longer have AC profiles and so cannot be considered as recent soils; by their friable consistence, crumb structures in the A horizons and fine nutty and crumb structures in the B horizons, have a greater similarity with the yellow-brown earths than with the yellow-grey earths, despite their occurrence in the yellow-grey earth zone. Similarly, there appears to be inadequate allocation for the positioning, within this classification, of the shallow litho-solic-like soils such as the Tekoa profile recorded in Appendix 1.

In relation to the major groups, the following are points of divergence from the general chemical and mineralogical trends recorded by Soil Bureau Staff (1968b):

Soils
Levee

Soils
and Y

Soils
and Rc

Soils
Steep

1 -

s,

Table 17 - Comparison of Soils of the Mowbray Area Classified Physiographically, Genetically and Constitutionally

	Common Genetic Classification	Technical Genetic Classification	Constitutional Classification
Soils of the Floodplains, Levees and Bottomlands			
Tasman series	Recent soil on alluvium	Luvic soil	
Wakanui series	Dry-hygrous YGE	Madenti-pallic soil	
Taitapu series	Gley recent soil	Madenti-luvic soil	
Soils of the Terraces and Younger Fans			
Ashwick series)		)	
Mowbray series)	Subhygrous YG-YBE intergrade	) Palli-fulvic soils	
Meikleburn series)		Fulvi-pallic soil	
Soils of the Older Fans and Rolling Hillsides			
Sherwood series)	Subhygrous YGE	) Pallic soils	) chloro-Illosols
Opuha series)		)	)
Clayton series		Madenti-fulvi-pallic soil	
Skipton series)	Dry-hygrous YG-YBE intergrade	Fulvi-pallic soil	hallo-Illosol
Kakahu series)		) Palli-fulvic soil	Chloro-Illosol
(Kakahu hill soil))		)	illo-Chlorosol
Soils of the Hilly and Steep Hillsides			
Tengawai series)	Subhygrous YGE	Clini-pallic soil	
(Tengawai hill soil))		Lithi-pallic soil	Hallo-Illosols - chloro-Illosols
Lookout series)	Hygrous upland and high country YBE	Lithi-eldefulvic soil	chloro-Illosol
Puketeraki series)		) Eldefulvic soils	chloro - 1 Vermosol
(Puketeraki hill soil))		)	illo - 2 Vermosol
Tekoa series)	Dry-hygrous upland and high country YBE		chloro-Illosol
Kaikoura series)		) Clini-lithi-eldefulvic soils	1 Vermo-Chlorosol
(Kaikoura hill soils))		Lithi-eldefulvic soil	chloro - 1 Vermosol
Kirkliston series)		Eldefulvic soil	

(i) Yellow-grey earths, in the Mowbray catchment -

1. C.E.C. is medium in the A horizon and declines in the B horizon, rising again in the C (or BC) / C horizon.

2. There is a rise in exchangeable Mg^{2+} and Na^{+} in the lower profile of the yellow-grey earths (and yellow-grey to yellow-brown earths intergrade) developed from loess over an older loess, but this trend is not parallelled in the stony yellow-grey earths on hilly and steep lands.

3. The presence of the fragipan is accompanied by lower levels of K^{+} than in the solum above, and this is considered to be further evidence in support of the idea that his feature is an older compact loess layer rather than a fragipan of genesis in the current cycle.

4. B horizons of the soils developed from loess have higher levels of expanding micaceous clays than their A horizons, but this may be due to inheritance from the underlying compact loess, which commonly has even higher levels of such clays, than the horizons above. The reverse trend is apparent in the stony yellow-grey earths on hilly and steep lands.

(ii) The yellow-grey earth to yellow-brown earths intergrade show similar trends to those noted above. In addition they show an abrupt decrease in total P below the A horizon - a requirement noted by Soil Bureau Staff (1968b).

(iii) Upland and high country yellow-brown earths in the Mowbray catchment show similar trends in chemistry and mineralogy to those outlined by Soil Bureau Staff (1968b). Exceptions, however, are where these soils intergrade to lithosols. Such intergrades show:

1. increasing levels of exchangeable bases and B.S.% with increasing profile depth;

2. in particular, increasing levels of exchangeable K^+ with increasing depth, a situation typical of the high country yellow-brown earth zone.

(c) The technical genetic classification provides a much greater definity at higher and mid-levels of classification and is capable of separating soils of only general similarity which were grouped together by the common genetic classification. By taking the technical classification to the lowest levels, it is possible to identify individual soil types in terms of morphology and soil forming processes (Appendix 1).

(d) The constitutional classification has a capability for indicating the direction of genesis and genetic stage attained by a soil. It can be useful in indicating poly-genesis and buried horizons. It is limited, however, by the sophisticated techniques required for the provision of data for its functioning, and it is because of this limitation, that only some of the soils of the Mowbray catchment have been so classified (Tables 14 and 17).

On the basis of constitutional assessment of the A horizons it is possible to show the similarity of stage of development attained by soils in different environments, and in particular to show the basic mineralogical similarity between recent loess deposits and greywacke colluvial debris. By continuing this examination into the B and C horizons, it is possible to trace the course of previous soil development and so by inference identify those soils which have either recently been rejuvenated or those which have not been subjected to recent accumulations of fresh material.

CHAPTER X

SUMMARY

The various survey techniques employed during the detailed soil survey of the Mowbray catchment have been discussed. Particular emphasis has been placed on the use of aerial-photographic interpretation in the delineation of the soil pattern and the preparation of the soil map at a scale of 20 chains to one inch. Aerial photographs provided a satisfactory base for the rapid identification of soil mapping units on the basis of the air-photo aspect of their surface features. Preliminary traverses, where possible aided by aerial reconnaissance served as a platform on which to establish a satisfactory terrain/photo-aspect key. Later detailed traverse over pre-selected routes enabled the characterisation of units established and revealed the range of soil individuals likely to be encountered within each unit.

Because of initial correlation difficulties, the soils were mapped according to a temporary legend which provided differentiation on the basis of parent material, topography, drainage, morphological development and the arrangement of horizons. Once the field data had been assembled and the results of chemical analyses were available correlation with existing, established soil units was carried out subjectively with the aid of a correlation table.

Samples were collected from the major genetic horizons of 15 profiles (14 on a volume weight basis) and these were subjected to routine chemical analyses. A rapid phosphorus fractionation was carried out and this yielded the information:

$$P_T = Pa + Po + Pf$$

In addition X-ray diffractograms were prepared of the A, B and C horizons of each profile. The presence or absence of metahalloysite and gibbsite, suspected on the X-ray diffractograms, was checked with DTA and IR techniques.

The factors of the present and past environment of the Mowbray catchment have been discussed. Particular attention has been paid to vegetation changes since the Otiran glaciation. Periods during which rapid sedimentation formed fans and terraces, have been related to similar periodic depositions on the Canterbury Plains, and to events on the rolling, hilly and steeplands of the catchment. The significance of such post-glacial events in the formation of surfaces of pedological development has been outlined. Four periods of sedimentation and erosion have been recorded. They occurr in immediate post-Otiran times, about 6,400 years, 2,500 years and 900 years ago.

The environmental and morphological ranges of the following series, which occur in the catchment have been discussed:

Yellow-grey earths -

Wakanui series
Sherwood series
Opuha series
Tengawai series

Yellow-grey earth to yellow-brown earths intergrade -

Ashwick series
Mowbray series*
Meikleburn series*
Clayton series*
Skipton series
Kakahu series

Upland and high country yellow-brown earths -
(and intergrades to skeletal soils)

Lookout series*
Puketeraki series
Tekoa series
Kaikoura series
Kirkliston series

Gley recent soils -

Taitapu series

Recent soils -

Tasman series

* Four new soil series were proposed to cover soils which were sufficiently distinct from related series to warrant differentiation at greater than type or variant level.

The variability likely to be encountered within these series was investigated by selected very detailed quadrats and traverses. Their classification in terms of the common genetic, technical genetic and constitutional systems have been discussed. The advantages of each system in relation to the soils of the Mowbray catchment are outlined.

The processes and factors of soil formation influencing the direction and degree of development of the soils of the catchment have been discussed in some detail. The processes of the "drift regime" have exerted the greatest influence in the formation of the soils of the area. Soils developed on alluvium are considered to form a hydro-chrono-sequence ranging from the present to early post-glacial times. The soils derived from loess, which blankets the older fan surfaces and downlands, form a complex of inter-related, topo-climo-hydro-sequences. The loess from which they are derived is considered to be of post-glacial origin and rests upon pre-weathered loess or mixed loess and colluvium of late

Otiran age. On the steeper hillsides, soils derived from essentially colluvial slope debris deposits, have been subjected to active mixing, erosion, accumulation and renewal by the introduction of fresh detritus at various times in the post-glacial period. Relatively stable sites on ridge crests indicate the current stage of weathering since the disappearance of permanent snow above 3500 ft about 10,000 years ago, and point to a fair degree of stability in the soils on steep slopes. A small area of Kirkliston series reveals the extent of soil development reached during the last interstadial and the ensuing period.

The soils of the Mowbray catchment are unique in that they form a bridge between the soils of the coastal downs and plains and the high country, glacially influenced, basins. They show that even small river valley systems are capable of producing considerable quantities of loess and reveal that while steepland high country soils are potentially unstable, the normal situation is one of stability.

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APPENDICES

Appendix.

APPENDIX 1

Detailed Profile Descriptions of Each Series and Chemical and Mineralogical Data of Selected Profiles

1. Terminology used in site and profile descriptions is based on that proposed by Taylor & Pohlen (1962) with amendments and additions outlined in Chapter III. 1. (4), pages 43 - 47, of this report.

2. Chemical and mineralogical techniques employed are based on Metson (1960) and Claridge (1969), with amendments and additions as oulined in Chapter III 4. pages 57 - 61, of this report.

3. Frequencies of crystalline clay minerals are indicated as follows -

A	=	50%	very abundant
a	=	30 - 50%	abundant
C	=	10- 29%	very common
c	=	5 - 9%	common
S	=	1 - 4%	scarce
R	=	1%	rare
P	=	presence noted but not determined quantitatively	

4. The total for Interlayered Hydrous Micas includes both illite-vermiculite intergrades and interlayered chlorites.

Profile No: MC.5

Soil type: Tasman sandy silt loam (Tasman series)

Location: About 600 yards south-east of Meikleburn Homestead on the lower part of the Mowbray fan.

Map sheet: S.90. Grid reference: 53651280.

Terrain: Level. Slope: 2^{o}.

Landform: Toe of Mowbray fan overlain by recent flood gravels from the Mowbray river.

Aspect: Level. Elevation: 1840' asl.

Drainage - site: Very well drained.
internal: Well drained - rapid through drainage.

Vegetation-present: Brown top, scattered hard & silver tussock, matagouri.
past: Probably poor Podocarp forest followed by tall tussock grassland.

Rainfall: 28".

Parent Material: Coarse greywacke alluvium.

A_{11} 0 - 3" Very dark greyish brown (2.5Y3/2); sandy silt loam; very friable; moderate root binding; moderate fine crumb and fine granular; abundant roots; few casts; very porous; rare sub-rounded stones and small boulders right to surface; grey and powdery when dry; indistinct boundary-

A_{12} 3 - 5" Dark greyish brown (2.5Y4/2); sandy silt loam; very friable; weak fine nutty breaking to fine crumb and fitting fine granular; many roots; few casts; common fine pores; rare rounded greywacke gravels and sub-rounded stones; distinct boundary to -

AC 5-- 11" Brown (10YR4/3); very stony sandy loam; loose; very weak fine granular tending to fine crumb; many roots; very porous; very stony subrounded and rounded greywacke gravels and stones and small boulders; merging to -

C 11"+ Brown (10YR4/3) extremely stony loamy sand; loose and structureless; few roots; very porous; extremely stony rounded greywacke gravels and stones and subrounded small boulders.

Technical Classification: Subhygrous to dry-hygrous moderately to strongly enleached luvic soil from weakly argillised greywacke alluvium.

Profile no: MC. 32.

Soil type: Wakanui silt loam (Wakanui series).

Location: Just east of Kirke's Road on the Meikleburn floodplain.

Map sheet: S.90. Grid reference: 52951205.

Terrain: Level. Slope: 1^{o}.

Landform: Appears to be an old floodplain of the Meikleburn.

Aspect: N.N.W. Elevation: 1870' asl.

Drainage-site: Imperfect. -internal: Somewhat impeded.

Vegetation: Carex sp., brown top and white clover.

Rainfall: 28".

Parent material: Fine greywacke alluvium and resorted loess.

A_{11} 0 - 3" Very dark greyish brown (10YR3/2); silt loam; very friable to loose; strong medium and fine granular and weak fine crumb; abundant roots; few distinct casts; indistinct boundary to -

A_{12} 3 - 8" Very dark greyish brown (10YR3.5/1.5); silt loam; very friable to friable (peds friable); strong very fine nutty with fitting and non-fitting fine and medium granular; many roots and casts; rare channels; few fine distinct dark brown linings in root channels; diffuse boundary to -

$IIB_{1}g$ 8 -12" Grey (10YR5/1); heavy silt loam; friable (peds friable to firm); weak to moderate fine and medium nutty; common roots; few casts; few channels; common fine distinct dark yellowish brown and olive brown mottles; rare reddish brown linings in root channels and pores; irregular and diffuse boundary to -

$IIB_{2}g$ 12-16" Grey (10YR5/1); silty clay loam; friable (peds friable to firm); very weak coarse blocky tending to form coarse prisms on drying; rare roots; few casts; few channels; many fine and medium prominent yellowish brown mottles; pale yellow surrounds to root channels; indistinct boundary to -

$IIB_{3}g$ 16-21" Pale olive brown (5Y6/2); very fine sandy clay loam; friable to firm; structureless but probable tendency to form weak prisms on drying; rare roots; rare channels; common fine and medium pores; many fine and medium yellowish brown vertical streaks; indistinct-

$IIIC_{1}g$ 21-26" Pale olive brown (5Y6/2); sandy loam; friable; structureless; rare roots; few channels; common fine and medium pores; many fine and medium yellowish brown vertical streaks; indistinct boundary to -

IVC$_2$ 26" + Light brownish grey (10YR6/2); stony loamy sand; very friable; weak crumb-loke aggregation; common fine Mn specks; common fine and medium yellowish brown mottles; stony with sub-rounded greywacke gravels to large stones.

<u>Technical classification</u>: Weakly enleached, moderately gleyed, madenti - pallic soil with very weakly developed fragipan from greywacke loess and fine alluvium.

Profile no: MC. 51.

Soil type: Taitapu silt loam (Taitapu series).

Location: About 250 yards south of the Meikleburn bridge and just to the east of Kirke's Road.

Map sheet: S.90. Grid reference: 52801245.

Terrain: Level. Slope: 0.5^{o}.

Landform: Floodplain of the Meikleburn - about 2 - 3' above current channels.

Aspect: Level. Elevation: 1850' asl.

Drainage-site: Imperfect-only slowly draining.

-internal: Poorly drained-waterlevel at 20".

Vegetation: Reeds, red and hard tussocks, brown top, sweet vernal and Yorkshire fog dominant.

Rainfall: 28".

Parent material: Recent fine alluvial sediments.

A_{11} 0 - 3" Very dark greyish brown (10YR3/2-4/1); silt loam; very friable; strong root binding; moderate medium and fine fine granular; abundant roots; few casts; porous; common unstained quartz grains; indistinct boundary to-

A_{12} 3 - 7" Dark grey (10YR4.5/1); silt loam; friable; moderate root binding; moderate to strong fine and very fine nutty and moderate fitting fine granular; many roots; few cast granules; common fine channels; few pores; few unstained quartz grains; common (5%) fine distinct grey and yellowish red streaks along root channels; irregular and diffuse boundary to -

IIABg 7 -10" Grey (10YR5/1); sandy silt loam; friable to very friable; weak root binding; moderate to strong medium and fine nutty and moderate fine cast granular; common roots; common casts of A12 material; common old and existing root channels; few to common fine pores; many (20%) fine prominent very pale brown, light yellowish brown and yellowish red streaks along channels: irregular and diffuse boundary to-

II(B)G 10-14" Greenish grey (5GY6/1); loam to silt loam; friable to very friable; weak to moderate medium and fine nutty; rare roots; common casts of ABg material; common channels; common to many fine and medium pores; many (50%) fine and medium prominent very pale brown and brownish yellow mottles giving variegated appearance; indistinct boundary to -

III(BC)G 14-18" Greenish grey (5GY6/1); sandy clay loam; friable to very friable; weak and moderate coarse and medium nutty to blocky tending to weak prismatic on drying; common channels; many pores; many (50%) fine and medium prominent yellowish brown and light grey mottles; distinct boundary to -

IVCG 18" + Variegated light grey (5Y6/1) and yellowish brown (10YR5/6); loamy sand to sandy loam; friable to very friable; very weak coarse nutty; common channels; many pores.

Technical classification: Hydrous, very weakly enleached, madenti-luvic soil from sub-moderately argillised greywacke alluvium and resorted loess.

Profile no: MC.82.

Soil type: Ashwick silt loam. (Ashwick series).

Location: Beside two obvious poplars on the centre of the Mowbray gorge.

Map sheet: S.91. Grid reference: 56300770.

Terrain: Gently sloping. Slope: 5^{o}.

Landform: Strongly dissected low fan on the north side of Lucas's hill.

Aspect: N.E. Elevation: 2300' asl.

Drainage-site: Well drained. -internal: Well drained.

Vegetation: Brown top, mouse ear, sweet vernal, scattered matagouri and snow tussock. Previously Podocarp forest and tall tussock grassland.

Rainfall: 31".

Parent material: Greywacke debris and slope-wash from adjacent hillside.

A_{11} 0 -2½" Greyish brown (dry 2.5Y5/2); gritty silt loam; loose to slightly hard; some peds hard; moderate root binding; moderate to strong fine granular; abundant roots; few fine casts; porous; indistinct boundary to-

A_{12} 2½- 6" Dark greyish brown (2.5Y4/2); gritty silt loam; very friable to friable; some peds firm; strong fine granular and weak fine crumb; abundant roots; common cast granules; porous; few subangular moderately weathered argillite gravels and small stones; indistinct boundary to -

AB 6 - 8" Yellowish brown (slightly dry 10YR5/4); gritty silt loam; very friable to friable; some peds firm; strong medium and fine granular, moderate to weak very fine nutty and weak fine crumb; many roots; many casts as inclusions of A12; porous; few subangular weakly weathered argillite gravels and small stones; indistinct boundary to -

BC 8 -11" Yellowish brown (10YR5/4); stony gritty silt loam; friable to firm; moderate to strong medium and fine granular and weak to moderate fine and very fine nutty; many roots; many casts as inclusions of AB; porous; stony subangular greywacke and argillite gravels and stones; distinct boundary to -

uB_{2} 11-17" Light yellowish brown (2.5Y6/4); gritty heavy silt loam; friable; weak fine nutty breaking to moderate medium and fine granular; few roots; few casts as inclusions of BC; common fine channels; few to common fine pores; few fine distinct yellowish brown mottles from decomposing stones; few subangular moderately to strongly weathered greywacke gravels and stones; indistinct boundary, merging to -

uBC 17" + Light yellowish brown (2.5Y6/4); stony silt loam; moderately compact; peds firm; weak medium and fine nutty; rare roots; common fine channels; common fine pores; few fine distinct yellowish brown mottles from decomposing stones; stony subangular moderately weathered greywacke gravels to large stones increasing with depth.

Technical classification: Strongly enleached (some weakly iron illuvial) palli-fulvic soil from weakly and moderately argillised greywacke and argillite gravels and sub-moderately argillised loess.

Profile No: MC.18.

Soil type: Mowbray silt loam (Ashwick set)

Location: On second distinct terrace of Mowbray about 40 yards south of S.E. boundary of Meikleburn station.

Map sheet: S.91. Grid reference: 55459910.

Terrain: Level. Slope: 1^{o}.

Landform: Terrace on edge of low-level fan.

Aspect: Level. Elevation: 2095' asl.

Drainage - site: Well drained; - internal: Very well drained.

Vegetation-present: Brown top, mouse ear, hard tussock and scattered matagouri.

past: Scattered Podocarp forest followed by tall tussock grassland.

Rainfall: 30".

Parent material: Coarse greywacke alluvium and greywacke loess.

A11 0 -2½ Very dark greyish brown (2.5Y3/2); loam to silt loam; very friable to friable (peds friable); strong medium and fine granular; moderate root binding; many roots; porous; few cast granules; rare fine rounded gravels; indistinct boundary to -

A_{12} 2½- 6" Drak greyish brown (2.5Y3.5/3); silt loam; very friable (peds friable); weak root binding; weak fine nutty and moderate to strong medium and fine fitting and non-fitting granular; many cast granules; few pores; many roots; rare rounded gravels; indistinct boundary to -

(B) 6 -13" Olive brown (2.5Y4/4); very stony silt loam; very friable; very weak fine nutty and fine grabular; many roots; very porous; few cast granules; very stony rounded and sub-rp rounded gravels to small boulders of greywacke alluvium; indistinct boundary to -

(B)C 13-"+ Olive brown (2.5Y4/4); extremely stony sandy loam; loose to very friable; structureless; extremely stony rounded and sub-rounded gravels to small boulders.

Large stones and scattered boulders may occur right to andon the surface.

Technical classification: Strongly enleached palli-fulvic soil from weakly argillised greywacke alluvium and sub-moderately argillised loess.

Profile no: MC.46

Soil type: Meikleburn silt loam (Ashwick set).

Location: Upper part of Orari fan bbout 600 yards WNW of Meikleburn homestead.

Map sheet: S.90. Grid reference: 51951395.

Terrain: Level. Slope: 1^0.

Landform: Low-level fan.

Aspect: Level. Elevation: 1920' asl.

Vegetation-present: Snow tussock, hard and silver tussock, sweet vernal and brown top.

past: Tall tussock grassland with scattered Podocarps.

Rainfall: 28".

Parent material: Greywacke alluvium and rewashed loess.

A_{11} 0 -2½" Dark greyish brown (2.5Y3.5/2) silt loam (with grits); loose to very friable; moderate to strong fine crumb and fine granular; abundant roots; few casts; rare fine channels; few fine white insect nests; porous; indistinct boundary to -

A_{12} 2½- 6" Dark greyish brown (2.5Y4/2); silt loam (with grits); very friable; moderate fine crumb and fine granular, tending to very weak fine nutty; many roots; few casts; few fine channels; porous; indistinct boundary to -

AB 6 - 9" Brown (2.5Y4/3); gritty silt loam; very friable; moderate to weak fine nutty and moderate fine crumb and fine granular; many casts; few roots; few channels; few to common fine pores; distinct boundary to -

B_{21} 6 -14" Dark olive brown (2.5Y4/4); gritty silt loam; friable; weak to moderate medium and fine nutty and fine granular and crumb; common roots; few cast granules; few fine channels; few to common fine pores; indistinct boundary to -

B_{22} 13-19" Light yellowish brown (2.5Y6/4); gritty silt loam; friable weak medium and fine nutty with some fine cast granules and some fine crumb; few roots; few fine channels; common fine pores; merging to -

C 19" + Light yellowish brown (2.5Y6/4); stony loam; friable to firm; stony to very stony sub-rounded gravel to large stones of very weakly weathered greywacke.

Technical classification: Very strongly enleached fulvi-pallic soil from moderately argillised greywacke gravels and sub-moderately argillised greywacke loess.

Profile no: MC.53.

Soil type: Sherwood silt loam. (Sherwood series).

Location: About 700 yards NE of the south-western corner of Meikleburn station.

Map sheet: S.90. Grid reference: 51551075.

Terrain: Gently sloping. Slope: 5.5°.

Landform: Low fan.

Aspect: Northerly. Elevation: 2020' asl.

Drainage-site: Well drained. -internal: Moderately well drained.

Vegetation-present: Poor pasture with short and tall tussock.

-past: Podocarp forest followed by tall tussock.

Rainfall: 30".

Parent material: Loess.

A_{11} 0 - 2" Very dark greyish brown (10YR3/2); dry 10YR5.5/1; silt loam; loose to very friable (peds very friable); strong root binding; moderate fine granular and fine crumb; loose and powdery when dry; abundant fine roots; few casts; porous; on drying shows rare fine light olive grey spots; indistinct boundary to -

A_{12} 2 - 5" Dark greyish brown (2.5Y4/2), dry 2.5Y6/2; silt loam; very friable (peds friable); weak root binding; strong very fine nutty and fitting medium and fine granular; many cast granules; many roots; common inclusions of AB; few channels; few pores; indistinct irregular boundary to -

AB 5 - 8" Olive brown (2.5Y4/3), dry 3.5Y7/3; silt loam; very friable to friable (peds friable); strong very fine nutty and fitting medium and fine granular, many as cast granules; many roots; common fine channels; few pores; rare fine prominent yellowish red spots from decomposing stones (or concretions); distinct boundary to -

B_{21} 8 -13" Light yellowish brown (2.5Y6/4), dry 5Y7/3; heavy silt loam; friable (peds friable to firm); moderate medium and fine nutty and some fine granular; common roots; common casts as inclusions of AB; few channels common fine pores; few very thin clayskins (3.5Y6/3) lining pores and channels; rare fine distinct brownish yellow and orange mottles from decomposing stones (or concretions); indistinct boundary to -

B_{22} 13-18" Light yellowish brown (3Y6/4), dry 5Y7/3; silty clay loam; friable to firm (peds firm); moderate medium and fine nutty; few roots; few casts;

common fine channels; common fine pores; few very thin clayskins (3.5Y6/3) in pores and channels; common fine faint brownish yellow and pale yellow vertical streaks along roots and channels; distinct irregular boundary to -

Dx 18-24"+ Pale olive (4Y6/4), dry 5Y7/3; silt loam; compact and massive; rare casts; many fine channels; many pores; common brown (7.5YR5/4) clayskins lining pores and channels; common fine and medium distinct light grey and few strong brown spots and vertical streaks.

<u>Technical classification</u>: Very strongly enleached, weakly clay illuvial, subgammate, weakly gleyed pallic soil with moderately developed fragipan, from moderately argillised greywacke loess.

Profile No: MC 53 Soil Type: SHERWOOD SILT LOAM

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq % Ca	Mg	K	Na
1	1-4	5.1	3.7	0.21	18	11.10	1.32	12	0.6	0.4	0.21	0.1
B	5-7	5.1	2.5	0.15	17	9.78	0.76	8	0.3	0.2	0.18	0.1
21	9-12	5.3	0.9	0.08	11	7.24	0.57	8	0.2	0.1	0.12	0.1
22	14-17	5.4	0.4	0.04	11	7.76	0.99	13	0.5	0.3	0.08	0.1
	19-22	5.7	0.5	0.03	16	8.56	1.84	21	0.9	0.7	0.05	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
1	203	597	91	891
B	164	471	139	774
21	173	352	103	628
22	134	191	85	410
	199	116	19	334

Whole Soil Gravel	Stones	% On fine earth Sand	Silt	Clay
-	-	34	44	22
-	-	nd	nd	nd
-	-	41	37	22
-	-	39	37	24
-	-	41	43	16

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
1	c	C	a	C	C	-	-	-	c	c
21	C	C	C	C	C	-	C	-	c	c
22	C	C	C	C	C	-	-	-	c	c
	c	a	C	C	c	-	-	-	c	c

Profile no: MC.79.

Soil type: Opuha hill soil (silt loam), Opuha series.

Location: On side of Lucas's hill about 400 yards south of the gate on the track to the Mowbray rain gauge.

Map sheet: S.91. Grid reference: 55900815.

Terrain: Moderately steep. Slope: 18^{o}

Landform: Mid-slope on strongly sloping ridge side.

Aspect: NNW. Elevation: 2350'asl.

Drainage-site: Moderately well drained.

-internal: Moderately well drained but somewhat impeded below 22".

Vegetation-present: Brown top, sweet vernal and mouse ear, with rare sweet briar, hard tussock and matagouri.

-past: Podocarp forest followed by tall tussock.

Rainfall: 33".

Parent material: Loess with a slight admixture of greywacke slope debris.

A_{11}	0 - $1\frac{1}{2}$"	Very dark greyish brown (10YR3/2); silt loam; very friable; weak root binding; moderate to strong fine granular and weak fine crumb; abundant roots; few casts; few fine white insect nests; porous; indistinct boundary to -
A_{12}	$1\frac{1}{2}$ - 6"	Very dark greyish brown (2.5Y3/2), dry 2.5Y5.5/2; silt loam; very friable to friable; moderate fine and very fine nutty breaking to moderate to strong medium and fine granular and weak fine crumb; abundant roots; common casts; common insect nests; rare fine channels; few to common fine pores; few moderately weathered angular greywacke stones along base of horizon; indistinct boundary to -
AB	6 -10"	Dark greyish brown (2.5Y4.5/2), dry 2.5Y6.5/2; silt loam; very friable to friable (peds friable); moderate medium and fine nutty breaking to fitting strong medium and fine granular; many roots; many cast granules; common insect nests; rare fine channels; few to common fine pores; few angular moderately weathered stones; distinct boundary to-
B_2	10-16"	Light yellowish brown (3.5Y6/3), dry 5Y7/3; slightly heavy silt loam; very friable to friable; weak to moderate medium and fine nutty and fine granular; tendency to fine platey; few roots; few casts; rare fine channels; few to common fine pores; rare angular moderately weathered stones; indistinct -

BC	16-22"	Light yellowish brown (3.5Y6/3), dry 5Y7/3; slightly heavy silt loam; very friable to friable; weak to moderate medium nutty tending to form fine platey; rare roots; rare channels; few insect nests; few to common pores; few angular moderately weathered greywacke stones; distinct boundary to -
D(x)	22" +	Pale olive (5Y6/3), dry 5Y7/2.5; slightly heavy silt loam; slightly compact; peds firm to very firm; weak coarse nutty tending to coarse prismatic on drying; weak platey fracture; rare roots; common medium and fine channels; few to common pores; common fine and medium distinct light grey and light yellowish brown and prominent yellowish brown mottles; rare angular moderately weathered greywacke stones; some dark brown Mn coatings on surfaces of some stones and lining some fissures.

No reaction to allophane field test in either the AB or D.

Technical classification: Moderately to strongly enleached, weakly gleyed, weakly subgammate pallic soil with weakly developed fragipan, from sub-moderately argillised loess and moderately argillised greywacke.

Profile No: MC 79 Soil Type: Opuha hill soil (silt loam) 30 6

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	2-6	5.6	3.7	0.19	20	12.22	6.89	56	4.4	1.9	0.38	0.1
B_1	8-10	5.7	1.8	0.14	13	10.10	5.82	58	3.9	1.5	0.31	0.1
B_2	12-14	5.5	1.5	0.10	15	8.62	3.67	43	2.2	1.2	0.24	0.1
BC	16-20	5.6	0.9	0.06	15	8.10	3.11	38	1.8	1.0	0.14	0.1
	24-26	5.8	0.4	0.03	14	7.91	3.04	38	1.7	1.1	0.08	0.2

	Pa ppm	Po ppm	Pf ppm	Pt ppm	Whole Soil %		% On fine earth		
					Gravel	Stones	Sand	Silt	Clay
A_1	114	524	59	697	-	1	41	36	23
B_1	81	369	103	553	1	34	nd	nd	nd
B_2	60	330	47	437	1	2	43	36	21
BC	53	130	26	209	1	3	40	37	23
	53	115	67	215	1	-	44	39	17

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	c	a	C	S	c	-	C	-	c	c
B_2	c	a	C	c	S	-	C	-	S	c
BC	c	a	C	c	c	-	C	-	c	c
	c	C	C	c	C	-	C	-	c	c

Profile no: MC.87.

Soil type: Clayton silt loam (Skipton set)

Location: About 350 yards south of Meikleburn homestead.

Map sheet: S.90. Grid reference: 53301285

Terrain: Very gently sloping. Slope: 3^o.

Landform: Shallow gully in footslope of concave part of hillside.

Aspect: ENE. Elevation: 1810' asl.

Drainage - site: Receiving site.

- internal: Poorly drained, water table at 16".

Vegetation - present: Scattered rushes and sedges - improved as clover rygrass pasture.

Rainfall: 28".

Parent material: Aeolian deposited and rewashed.

A_1	0 - 5"	Greyish brown (10YR5/2); silt loam; slightly plastic and sticky; moderate fine granular; many roots; few casts; few channels; common fine distinct dark brown mottles lining root channels; indistinct boundary to -
AB	5 -10"	Light brownish grey (10YR5.5/2); silt loam; friable to very friable (peds friable); weak to moderate fine and medium nutty breaking to strong very fine nutty and fitting fine granular; common roots; common small casts; few channels; many fine and medium prominent yellowish red and pale yellow mottles; distinct and irregular boundary to -
B_1g	10-16"	Variegated strong brown (7.5YR5/6) and pale olive brown (5Y6/2); heavy silt loam; friable; weak to moderate fine and medium nutty breaking to very fine nutty and fitting fine granular; few roots; common fine casts; few channels and pores; indistinct boundary to -
B_2G	16-21"	Light grey (2.5YN7/-); silty clay loam; friable to firm; moderate fine and medium blocky; rare roots; common fine channels and pores; discontinuous clayskins in channels and pores of pale yellow colour; few fine Mn specks; many fine to coarse prominent orange mottles; indistinct boundary to -
GCx	21" +	Variegated light grey (5Y7/1) and strong brown (7.5YR5/6) slightly gritty silty clay loam; moderately compact; massive but tending to show coarse blocky separation; few channels with Mn coated linings; discontinuous pale yellow clayskins in channels and common fine pores; many fine manganese specks and distinct vertical streaks.

Technical classification: Dry-hygrous, moderately enleached, strongly gleyed, weakly clay illuvial; gammate madenti-fulvi-pallic soil with moderately developed fragipan and from sub-moderately argillised greywacke loess.

Profile No: MC.89.

Soil type: Skipton silt loam (Skipton series)

Location: About 100,yards west of Trig M.

Map sheet: S.90. Grid reference: 53751025.

Terrain: Rolling. Slope: 12^{o}.

Landform: Moderately sloping convex hillside - upper mid-slope.

Aspect: West. Elevation: 2100;' asl.

Drainage - site: Moderately well drained but may tend to collect water during wetter periods.

- internal: Somwwhat impeded.

Vegetation - present: Hard tussock, brown top sweet vernal, mouse ear, snow tussock and scattered matagouri.

- past: Podocarp forest followed by tall tussock.

Rainfall: 30".

Parent material: Loess over compact loess.

A_{11} 0 -4½" Very dark greyish brown (2.5Y3/2); silt loam; very friable to friable; moderate root binding; moderate fine granular and some fine crumb; abundant roots; common cast granules; rare fine channels; porous; indistinct boundary to -

A_{12} 4½- 8" Very dark greyish brown (2.5Y3/2); silt loam; friable; moderate fine granular; many roots; common cast granules; rare fine channels; porous; few rounded and nodular iron concretions of very fine gravel size; irregular and distinct boundary to -

AB 8 -11" Yellowish brown (10YR5/4); silt loam; friable; moderate to strong fine nutty and medium cast granular; common roots; many casts as inclusions of A_{12}; rare fine channels; few to common fine pores; slightly stony with rounded Fe concretions and angular cherty greywacke gravels; irregular and diffuse boundary to-

B_2 11-16" Light yellowish brown (3.5Y6/3); gritty heavy silt loam; friable (peds friable to firm); weak to moderate fine and medium nutty breaking to moderate medium and fine granular; common roots; common cast granules; few fine channels; few to common fine pores; common rounded iron concretions and angular cherty greywacke gravels; diffuse boundary-

B_3cn 16-20" Light yellowish brown (2.5Y6/4); gritty silty clay loam; firm to very firm; weak fine and medium nutty; rare roots few casts; common fine and medium channels; common fine pores; continuous clayskins (5y6/2.5) in channels and thin discontinuous coatings on some peds; few fine Mn concretions; many fine and medium prominent pale olive and brownish yellow mottles; common rounded iron concretions and angular cherty greywacke gravels; diffuse boundary -

Cx 20" + Light yellowish brown (2.5Y6/4); silty clay loam; moderately compact; weak fine prismatic breaking to weak coarse blocky; few casts; common medium and fine channels; common fine and medium pores; discontinuous clayskins (2.5Y5/2) lining channels and pores; also along faces of prisms; many fine to coarse prominent grey, strong brown and white mottles.

Notes. 1. Diffuse zone of concretionary development occurs towrads the base of the BC (or B_3) horizon and in the upper part of the C horizon.

2. Concretions present in B_2 may have been inherited from a wider zone of concretionary development which existed in hhe past.

Technical classification: Moderately enleached, weakly to moderately clay illuvial, gammate, fulvi-pallic soil with concretions and moderately developed fragipan, from sub-moderately argillised loess.

Profile No: MC 89 Soil Type: Skipton silt loam

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-5	5.8	2.7	0.22	12	11.10	3.77	34	2.4	1.0	0.44	0.1
AB	8-11	5.7	1.2	0.15	8	9.30	2.20	24	1.1	0.7	0.31	0.1
B_2	11-16	5.6	0.6	0.06	10	7.82	2.19	28	1.1	0.8	0.14	0.1
B_3	16-20	5.9	0.2	0.03	8	10.20	3.36	33	1.9	1.3	0.07	0.1
C	24-26	6.1	0.2	0.03	7	9.94	3.73	38	2.0	1.5	0.04	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	191	561	79	831
AB	100	318	51	469
B_2	66	157	15	238
B_3	133	85	40	275
C	88	121	114	325

Whole Soil %		% On fine earth		
Gravel	Stones	Sand	Silt	Clay
-	-	43	34	23
1	-	nd	nd	nd
2	-	42	34	24
2	-	44	34	23
-	-	44	36	18

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	S	C	C	c	C	-	C	-	S	c
B_2	c	a	C	S	C	-	C	-	S	c
B_3	S	C	a	c	C	-	C	-	S	c
C	S	C	C	-	C	-	C	-	S	c

Profile No: MC.28.

Soil type: Kakahu silt loam (Kakahu series)

Location: About 600 yards south east of Meikleburn homestead.

Map sheet: S.90. Grid reference: 53351220.

Terrain: Moderately sloping. Slope: 11°.

Landform: Footslope of a low ridge.

Aspect: East. Elevation: 1850' asl.

Drainage - site: Well drained - internal: Moderately well drained.

Vegetation: Improved pasture - white clover, sweet vernal, brown top.
- previously tall tussock grassland.

Rainfall: 28".

Parent material: Loess over mixed loess and colluvial greywacke slope debris.

A_{11} 0 -2½" Very dark greyish brown (10YR3/2); silt loam; loose to very friable (peds very friable to friable); strong root binding; moderate medium and fine granular and fine crumb; abundant fine roots; few casts; very porous; indistinct boundary to -

A_{12} 2½- 6" Very dark greyish brown (2.5Y3/2); heavy silt loam; very friable (peds friable); moderate root binding; moderate very fine nutty; medium and fine fitting granular and some fine crumb; many roots; many casts from B1; few channels; few insect nests; very porous; irregular and distinct boundary to -

B_1 6 - 9" Light yellowish brown (2.5Y5.5/4); heavy silt loam; friable (peds friable to firm); strong fine and very fine nutty and medium and fine fitting granular; common roots; many casts of A12; few channels; few distinct pores; indistinct boundary to -

B_2 9 -13" Light yellowish brown (2.5Y6/4); silty clay loam; friable (peds friable to firm); very weak fine prismatic breaking to moderate fine and very fine nutty and fitting fine granular; few roots; few casts as inclusions of B1; common fine channels; few pores; few thin clayskins lining channels; distinct boundary to -

B_3 13-24" Pale yellow (2.5Y6.5/4); stony clay loam; friable (peds friable to firm); moderate medium to very fine nutty and some fine granular ; few roots; few casts; common channels; few pores; few thin clayskinsin voids around stones; stony gravel to large stones, unweathered to strongly weathered; distinct boundary to -

DCx 24" + Pale yellow (2.5Y6/4); gritty clay loam; compact and massive; rare casts; few channels; common fine pores;

few thin clayskins lining channels; common fine distinct brownish yellow and yellowish brown mottles from decomposing stones; few moderately weathered greywacke and quartz gravels and stones.

Technical classification: Moderately to strongly enleached subgammate palli-fulvic soil from weakly argillised greywacke loess and sub-moderately and moderately argillised greywacke colluvium.

Profile No: MC 28 Soil Type: **Kakahu silt loam**

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-6	5.3	3.9	0.20	19	12.85	4.68	36	3.0	1.3	0.28	0.1
B_1	6-9	5.4	2.0	0.13	16	10.31	3.40	33	2.1	1.0	0.21	0.0
B_2	11-13	5.4	1.6	0.10	16	9.47	2.62	28	1.6	0.8	0.19	0.1
B_3	16-19	5.5	1.0	0.07	14	8.99	2.72	30	1.6	0.8	0.19	0.1
C	24-27	5.7	0.5	0.03	16	10.42	5.28	51	3.5	1.6	0.12	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	140	517	18	675
B_1	78	390	48	516
B_2	66	312	10	388
B_3	63	267	57	387
C	41	176	70	287

	Whole Soil %		% On fine earth		
	Gravel	Stones	Sand	Silt	Clay
A_1	-	-	45	34	21
B_1	1	-	nd	nd	nd
B_2	12	10	48	33	19
B_3	25	11	nd	nd	nd
C	17	3	53	32	15

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	C	C	C	c	c	-	C	-	c	c
B_2	C	C	C	S	S	-	C	-	S	S
C	c	C	C	c	C	-	C	-	S	c

Profile no: MC.81.

Soil type: Kakahu hill soil (silt loam) - (Kakahu series)

Location: About 2 miles north of Fiery Peak on the south side of Lucas's hill.

Map sheet: S.91. Grid reference: 56500595.

Terrain: Moderately steep; Slope: 24°.

Landform: Footslope of strongly sloping convex hillside.

Aspect: East. Elevation: 2500' asl.

Drainage: Moderately well drained - shedding site.

Vegetation - present: Celmisia sp. matagouri, snow, hard and blue tussocks (similar to that in Plate 5).

- past: Tall tussock grassland following Podocarp/beech forest.

Rainfall: 33".

Parent material: Loess on mixed loess and colluvium on colluvium.

A_{11} 0 - 2" Greyish brown (2.5Y5/2), dry 2.5Y6/2; silt loam; very friable; weak root binding; moderate fine granular and weak fine crumb; abundant roots; few casts; porous; indistinct boundary to -

A_{12} 2 - 9" Dark greyish brown (2.5Y4/2); silt loam; very friable to friable; moderate to strong medium and fine granular with some moderate medium and fine nutty and weak fine crumb; abundant roots; common cast granules; few fine channels; few to common fine pores; indistinct -

AB 9 -13" Brown (10YR4.5/3.5), dry 2.5Y6.5/2; silt loam; friable; moderate medium and fine nutty and few cast granules; few fine channels; many roots; few to common fine pores; distinct and irregular boundary to -

B_{21} 13-16" Light yellowish brown (2.5Y6/4); silt loam; friable; moderate medium and fine nutty and few cast granules; common roots; few fine channels; common to few fine pores; few angular moderately to strongly weathered small greywacke stones; indistinct boundary to -

B_{22} 16-20" Light yellowish brown (2.5Y6/4), dry 5Y7/3; gritty silt loam; friable; weak to moderate fine and medium nutty and fine crumb; common roots; common fine channels; few to common fine pores; slightly stony angular moderately weathered greywacke gravels and stones; irregular and distinct boundary to -

BC 20-25" Light yellowish brown (2.5Y6/4), dry 5Y7/2.5; stony gritty silt loam; firm to very firm (peds friable); moderate to weak fine and medium blocky and some fine crumb; rare roots; common channels; common pores; stony to very stony moderately to strongly weathered angular greywacke gravels and stones; irregular and distinct -

Dr   25" +   Moderately to strongly weatherd greywacke break- into angular blocks.

Bare areas occur in regions between plants and these have a thin litter of decomposing tussock fragments.

Technical classification : Very strongly enleached, weakly sub-gammate palli-fulvic soil from sub-moderately arg-illised loess and sub-moderately to moderately argillised greywacke colluvial debris.

Profile No: MC 81 Soil Type: Kakahu hill soil (silt loam)

	Depth ~~inches~~	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A1	2-6	5.3	4.0	0.19	21	10.46	0.78	7	0.3	0.1	0.31	0.1
AB	9-13	5.3	5.1	0.23	22	12.47	1.62	13	0.7	0.3	0.56	0.1
B2	14-18	5.5	1.1	0.06	19	7.24	0.39	5	0.2	0.1	0.12	0.1
BC	20-22	5.4	0.6	0.05	13	5.28	0.29	5	0.1	0.0	0.06	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A1	166	372	140	678
AB	138	488	64	690
B2	310	212	165	687
BC	344	233	104	681

Whole Soil %		% On fine earth		
Gravel	Stones	Sand	Silt	Clay
2	-	43	37	20
-	-	nd	nd	nd
16	3	53	33	15
16	5	51	35	15

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmorillonite	metahalloysite	gibbsite	quartz	feldspar
A1	C	c	a	C	c	-	c	P	c	c
B2	C	C	C	C	S	-	C	P	c	c
BC	C	C	C	C	-	-	c	P	c	c

Profile no: MC.44.

Soil type: Tengawai hill soil (silt loam), (Tengawai series)

Location: About 30 yards on the south side of Tripp Pass.

Map sheet: S.90. Grid reference: 49251400.

Terrain: Moderately steep (hilly). Slope: 17°.

Landform: Upper slope of steep ridge on watershed.

Aspect: West. Elevation: 2200' asl.

Drainage: - site: Well drained - shedding site.
- internal: Moderately well drained.

Vegetation - present: Poor hill pasture of sweet vernal and brown top with scattered matagouri and tall tussock.
- past: Podocarp forest followed by tall tussock .

Rainfall: 30".

Parentmaterial: Thin accumulation of loess over mixed loess and colluvium on weathered greywacke in place.

A_{11} 0 - 3" Very dark greyish brown (2.5Y3/2); silt loam; very friable (peds very friable to friable); moderate root binding; moderate medium and fine granular and some fine crumb; abundant roots; common casts as inclusions of A12; rare fine channels, few insect nests; porous; indistinct boundary to -

A_{12} 3 -10" Dark greyish brown (2.5Y4/2); gritty heavy silt loam; friable; weak root binding; strong medium and fine granular and some very fine nutty; many roots; many casts as inclusions of AB; rare channels; few insect nests; porous; few angular gravels and stones of moderately to strongly weathered greywacke; irregular and distinct boundary to -

AB 10-14" Light yellowish brown (2.5Y5.5/4); gritty heavy silt loam; friable; weak root binding; strong medium and fine granularand very fine nutty; many roots; abundant casts as inclusions from A12; rare channels; common pores; slightly stony angular moderately to strongly weathered greywacke gravels and stones; indistinct -

B_2 14-20" Light yellowish brown (2.5YR6/4); stony heavy silt loam; firm; (peds friable to firm); moderate medium and fine nutty; common roots; rare casts; common fine channels; common pores; few very thin clayskins especially adjacent to stones; stony to very stony angular moderately to strongly weathered greywacke gravels and stones; irregular and distinct boundary to -

Dr 20" + Moderately to strongly weatherd greywacke.

Technical classification: Moderately to strongly enleached, weakly subgammate pallic soil from strongly argillised greywacke and sub-moderately argillised loess.

Profile No: MC 44 Soil Type: Tengawai hill soil (silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-6	5.4	4.0	0.24	17	12.68	5.23	41	2.6	1.7	0.90	0.1
AB	10-14	5.5	2.3	0.15	15	9.51	2.86	30	1.2	0.8	0.75	0.1
B_2	14-18	5.5	1.4	0.10	14	7.40	1.61	22	0.6	0.4	0.58	0.1
D	20-25	5.4	0.7	0.06	11	8.03	1.49	19	0.7	0.2	0.54	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	143	685	71	899
AB	68	508	28	604
B_2	43	405	40	488
D	88	256	102	446

Whole Soil%		% On fine earth		
Gravel	Stones	Sand	Silt	Clay
9	2	48	31	21
11	7	nd	nd	nd
14	10	51	33	16
9	63	48	31	21

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	c	C	C	c	c	-	C	-	c	c
B_2	c	C	C	c	S	-	C	-	S	S
D	S	C	C	C	-	-	C	-	S	c

Profile no: MC.72.

Soil type: Tengawai hill soil (stony silt loam), (Tengawai series)

Location: Footslope of ridge dividing the two main branches of the Mowbray River.

Map sheet: S.91. Grid reference: 57150630.

Terrain: Moderately steep. Slope: 19°.

Landform: Footslope of moderately to steeply sloping hillside.

Aspect: North. Elevation: 2400' asl.

Drainage - site: Well drained - shedding site.

- internal: Well drained.

Vegetation: -present: Hard and blue tussock, sweet vernal, brown top matagouri and scattered snow tussock.

-past: Podocarp forest followed by tall tussock.

Rainfall: 32".

Parent material: A thin accumulation of loess over mixed loess and grey wacke colluvial debris.

A_{11} 0 - $1\frac{1}{2}$" Dark greyish brown (10YR4/2); gritty silt loam; very friable; moderate root binding; moderate fine crumb and few fine granules; many roots; rare casts; rare channels; porous; few subangular gravels and small stones; indistinct boundary to -

A_{12} $1\frac{1}{2}$ - 4" Dark greyish brown (10YR4/2.5), dry 2.5Y6/2; gritty silt loam; very friable; weak root binding; moderate very fine and fine granular and fine crumb; many roots; common casts; rare channels; some white insect nests; few pores; rare subangular gravels and small stones; distinct boundary to -

AB 4 - 8" Brown (10YR4/3-5/4), dry 2.5Y6.5/2; stony gritty silt loam; very friable to friable (peds friable); moderate to strong very fine nutty and fine granular and some weak fine crumb; many roots; abundant fine cast granules; few channels; few pores; stony subangular moderately weathered gravels and small stones; indistinct boundary to -

B_1 8 - 12" Yellowish brown (10YR5/4), dry 2.5Y6.5/2; stony gritty heavy silt loam; very friable to friable (peds friable); moderate very fine nutty and fine granular; mnay roots; common fine cast granules; few channels and pores; stony subangular moderately weathered gravels and small stones; distinct boundary to -

B_2 12-18" Light yellowish brown (1Y6/4), dry 5Y7/3); stony gritty heavy silt loam; friable; weak to moderate medium to coarse nutty breaking to very fine nutty and fitting granular; few roots; rare casts; few channels; few pores; stony subangular and angular weakly to moderately weatherdd gravels to large stones; indistinct -

BC 18-24"+ Light yellowish brown (2.5YR6/4), dry 2.5Y8/4; very stony gritty heavy silt loam; weakly compacted (peds firm); moderate fine nutty and fitting fine granular; few roots; few channels; few pores; very stony subangular and angular moderately to weakly weathered gravels to small boulders.

Moderate to weak reaction to allophane field test in the BC horizon. Weak, slow reaction in the B_2.

Technical classification: Strongly enleached, weakly subgammate pallic to lithi-pallic soil from sub-moderately argillised greywacke colluvium and sub-moderately argillised loess.

Profile No: MC 72 Soil Type: Tengawai hill soil (stony silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-5	5.4	4.7	0.23	20	13.39	4.78	36	2.8	1.2	0.68	0.1
B_1	6-10	5.5	2.3	0.17	17	9.83	3.03	31	1.7	0.8	0.52	0.1
B_2	12-17	5.5	1.4	0.11	13	8.19	1.41	17	0.7	0.3	0.37	0.1
BC	18-21	5.5	2.2	0.14	16	9.01	2.07	23	1.1	0.6	0.28	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	161	511	87	759
B_1	106	456	131	693
B_2	120	393	112	625
BC	112	430	144	687

	Whole Soil%		% On fine earth		
	Gravel	Stones	Sand	Silt	Clay
A_1	20	-	44	31	25
B_1	27	25	nd	nd	nd
B_2	18	24	45	33	22
BC	22	26	44	31	25

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	c	C	C	C	c	-	C	P	c	S
B_2	C	C	C	C	-	-	C	P	S	S
BC	c	C	C	C	-	-	C	P	c	S

Profile no: MC.85.

Soil type: Tengawai hill soil (stony silt loam), (Tengawai series)

Location: West side of ridge running east from Tripp Pass.

Map sheet: S.90. Grid reference: 50401380.

Terrain: Moderately steep. Slope: 14^{o}.

Landform: Convex upper slope near crest of ridge.

Aspect: WNW. Elevation: 2380' asl.

Drainage - site: Well drained shedding site.

- internal: Moderately well drained.

Vegetation - present: Hard tussock, brown top, mouse ear and scattered tall tussock.

- past: Podocarp forest followed by tall tussock.

Rainfall: 30".

Parent material: Mixed colluvium and loess with thin cover of loess.

A_{11} 0 - 3" Very dark greyish brown (10YR2.5/2); silt loam; friable to very friable; strong root binding; moderate to strong fine granular and some fine crumb; abundant fine roots; few cast granules; few fine channels; some white insect nestsvery porous; few subangular moderately weathered greywacke stones; indistinct boundary to -

A_{12} 3 - 6" Very dark greyishbrown (2.5Y3/2); slightly gritty silt loam; friable; moderate root binding; strong medium and fine granular and fine crumb; abundant roots; common casts; few fine channels; common insect nests; very porous; few subangular moderately weathered greywacke stones; indistinct boundary to -

AB 6 - 9" Dark greyish brown (2.5Y4/2); stony silt loam; friable; strong medium and fine granular and very fine nutty; common roots; common casts; few fine channels; porous; slightly stony moderately weathered angular and subangular greywacke gravels and stones; distinct and irregular boundary to -

B_{21} 9 -13" Yellowish brown (1Y5/4); stony silt loam; friable; moderate medium and fine nutty breaking to moderate to strong very fine nutty and fine granular; common roots; common cast granules; common fine channels; porous; slightly stony moderately weathered angular and subangular greywacke gravels and stones; merging to -

B_{22} 13-16" Light yellowish brown (2Y5.5/4); stony slightly heavy silt loam; friable; moderate medium and fine nutty breaking to very fine nutty and fine granular; few roots; rare casts; rare fine channels; porous; stony moderately weathered angular greywacke gravels and stones; distinct boundary to -

B_3 16-25"+ Light yellowish brown (2.5Y6/4); slightly stony heavy silt loam (with grits); friable; moderate fine nutty and some fine granular; few roots; porous; slightly stony moderately weathered angular gravels to large stones of greywacke.

Slight stratification of stones in the B22 may indicate solifluction or may be due to deposition of colluvial material on an old surface.

<u>Technical classification</u>: Strongly enleached, non-gammate pallic to lithi-pallic soil from moderately argillised greywacke colluvium and sub-moderately argillised greywacke loess.

Profile No: MC 85 Soil Type: Tengawai hill soil (stony silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq % Ca	Mg	K	Na
A_1	1-5	5.1	6.0	0.38	16	17.13	6.52	38	3.7	1.5	1.25	0.1
AB	6-9	5.0	3.3	0.22	15	13.32	2.30	17	1.1	0.6	0.48	0.1
B_2	12-15	5.1	1.8	0.14	13	10.78	1.34	12	0.6	0.3	0.38	0.1
B_3	21-25	5.4	1.3	0.10	13	9.04	1.04	12	0.7	0.2	0.07	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	426	734	156	1316
AB	216	687	47	950
B_2	111	653	180	944
B_3	158	441	339	938

Whole Soil % Gravel	Stones	% On fine earth Sand	Silt	Clay
6	6	43	35	23
17	13	nd	nd	nd
12	12	37	38	25
15	33	40	35	25

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmorillonite	metahalloysite	gibbsite	quartz	feldspar
A_1	C	C	C	c	C	–	C	P	c	c
B_2	c	C	C	C	S	–	C	P	S	S
B_3	C	C	C	C	c	–	C	P	S	S

Profile no: MC.64.

Soil type: Lookout steepland soil (stony silt loam)

Soil set: Puketeraki.

Location: About 1 mile north of Fiery Peak on eastern boundary.

Map sheet: S.91. Grid reference: 56900425.

Terrain: Moderately steep to steep. Slope: 25^{0}.

Landform: Steeply sloping stable old high fan on ridge side.

Aspect: West. Elevation: 2800' asl.

Drainage:-site: Well drained-shedding site.

-internal: Well drained.

Vegetation - present: Snow tussock, *Celmisia sp*, matagouri, grasses and rare flax.

- past: Tall tussock grassland after Podocarp forest.

Rainfall: 35".

Parent material: Mixed loess and greywacke slope debris.

Few scattered large stones on the surface.

0_1 ½ - 0" Very thin discontinuous litter of dry snow-grass and grass fragments.

A_{11} 0 - 2" Brown (10YR4/3-slightly dry); gritty silt loam; loose to very friable; (peds very friable); moderate root binding; weak to moderate fine crumb and some fine granular; abundant roots; few casts; porous; few subangular gravels; indistinct boundary to -

A_{12} 2 - 8" Greyish brown (10YR5/2-slightly dry); very stony gritty silt loam; friable (peds friable and firm); moderate medium and fine granular and weak fine crumb; abundant roots; common casts; porous; very stony subangular and angular weakly to moderately weathered greywacke gravels and stones; indistinct boundary -

B_1 8 -11" Light yellowish brown (2.5Y5.5/4), dry 3.5Y7/3; very stony silt loam; friable (peds range very friable to firm); moderate fine granular and weak to moderate medium and fine nutty; common roots; common casts as inclusions from A1; few pores; very stony subangular and angular weakly to moderately weathered greywacke gravel and stones; indistinct boundary to -

BC 11-18" Light yellowish brown(2.5Y6/4), dry 5Y7/3; stony silt loam; friable; weak to moderatemedium and fine nutty; common roots; rare casts; few channels; common fine pores; stony gravel to large angular stones; distinct boundary to -

uB 18-24" Light yellowish brown (2.5Y6/4), dry 5Y7/3; gritty silt loam; friable; weak to moderate nutty; few roots; common fine channels; common fine pores; few subangular gravels; distinct boundary to -

uBC 24-32"+ Light yellowish brown(2.5Y6/4), dry 5Y6.5/3; stony heavy silt loam; friable to firm; (peds range friable to very firm); weak nutty and weak to moderate medium and fine crumb; rare roots; few channels; common pores; stony subangular gravel and angular large greywacke stones.

<u>Technical classification</u>: Very strongly enleached lithi-eldefulvic soil from sub-moderately argillised greywacke colluvium and loess over a truncated very strongly enleached eldefulvic soil from sub-moderately argillised loess and colluvium.

Profile No: MC 64   Soil Type: Lookout steepland soil (stony silt l'm)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-5	4.9	5.0	0.24	21	12.31	1.32	11	0.6	0.3	0.38	0.1
B_1	6-10	5.1	3.8	0.20	19	11.79	0.84	7	0.3	0.2	0.28	0.1
BC	13-17	5.3	1.7	0.10	17	7.56	0.21	3	0.1	0.0	0.05	0.1
uB	19-23	5.2	1.4	0.08	17	7.03	0.17	2	0.0	0.0	0.04	0.1
uBC	26-28	5.3	nd	nd	nd	6.66	0.21	3	0.1	0.0	0.07	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm	Whole Soil		On fine earth		
					Gravel	Stones	Sand	Silt	Clay
A_1	157	636	126	919	24	13	47	34	20
B_1	126	627	62	816	28	17	nd	nd	nd
BC	163	459	96	718	8	7	45	43	12
uB	192	428	117	737	4	-	45	39	16
uBC	314	391	89	794	28	6	53	32	16

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	c	c	c	c	c	-	-	P	c	c
BC	c	c	c	c	c	-	c	P	S	c
uB	c	c	c	S	c	-	c	P	S	c
uBC	c	c	c	-	c	-	c	P	S	c

Profile no: MC.69.

Soil type: Puketeraki steepland soil (stony silt loam).
(Puketeraki series)

Location: About 1 mile north of Fiery Top on eastern watershed.

Map sheet: S.91. Grid reference: 57350435.

Terrain: Steeply sloping. Slope: 33^{o}.

Lanform: Upper slope on side of steep ridge.

Aspect: SSW. Elevation: 3500' asl.

Drainage - site: Very well drained - shedding site.
- internal: Moderately well drained.

Vegetation - present: Snowtussock, blue tussock and Celmisia sp.
- past: Tall tussock grassalnd.

Rainfall: 35 - 40".

Parent material: Coarse greywacke colluvial debris with some wind-blown fines.

Thin discontinuous surface litter of dry snow tussock fragments.

A_{11} 0 -2½" Dark greyish brown (2.5Y4/2), dry 2.5Y6/2; stony gritty silt loam; loose and fluffy; weak to moderate fine granular and fine crumb; abundant roots; common fine casts; porous; stony subangular and angular moderately weathered greywacke gravels and small stones; indistinct boundary -

A_{12} 2½- 6" Dark greyish brown (2.5Y4/2), dry 2.5Y5/2; stony gritty silt loam; loose to very friable (peds very friable); moderate to weak medium and fine crumb and fine granular; abundant roots; common fine casts; porous; stony subangular and angular moderately weathered greywacke gravel and small stones; indistinct boundary to -

AB 6 -10" Olive brown (2.5Y4/3), dry 2.5Y5/2; gritty silt loam; very friable; moderate fine nutty and medium and fine crumb; common roots; few casts; few channels; porous; few subangular and angular moderately to strongly weathered gravels and stone; indistinct boundary to -

(B_2) 10-14" Light olive brown (2.5Y5/4), dry 2.5Y6/3; gritty heavy silt loam; friable; moderate fine nutty and fine and medium crumb; common roots; few casts; few channels; common fine pores; few subangular and angular moderately to strongly weathered greywacke stones; distinct -

BC 14-22"+ Light olive brown (2.5Y5/4); extremely stony gritty heavy silt loam; friable to firm; weak to moderate fine nutty and medium and fine crumb; few roots; few channels; common fine pores; extremely stony moderately weathered stones and boulders.

Technical classification: Very strongly enleached lithi-eldefulvic soil from moderately argillised greywacke slope debris and intermixed sub-moderately argillised loess.

Profile No: MC 69 Soil Type: Puketeraki steepland soil (sty silt 1'm)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	≤ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-5	5.2	7.7	0.37	21	13.43	1.43	11	0.6	0.3	0.49	0.1
AB	6-10	5.3	7.3	0.31	23	14.04	0.70	5	0.3	0.1	0.23	0.1
(B)	11-13	5.2	4.9	0.26	19	10.83	0.35	3	0.1	0.1	0.11	0.1
BC	17-20	5.1	4.9	0.25	19	11.97	0.57	5	0.3	0.1	0.08	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	189	529	329	1047
AB	132	648	212	992
(B)	74	594	100	768
BC	115	735	40	890

Whole Soil %		% On fine earth		
Gravel	Stones	Sand	Silt	Clay
46	-	59	27	18
13	3	nd	nd	nd
20	18	51	32	17
33	44	47	28	25

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	C	c	C	a	-	-	-	P	c	c
(B)	a	S	a	a	-	-	-	P	-	-
BC	c	c	C	a	C	-	c	P	c	c

Profile no: MC.84.

Soil type: Puketeraki hill soil (silt loam), Puketeraki series.

Location: On watershed about 400 yards west of Lookout peak.

Map sheet: S.91. Grid reference: 57300250.

Terrain: Moderately steep. Slope: 19^o.

Landform: Foot of convex shoulder on main ridge.

Aspect: West. Elevation: 4800' asl.

Drainage - site: Well drained - shedding site.

- internal: Moderately well drained.

Vegetation - present: Tall and blue tussock, rare Celmisia sp. much bare ground.

- past: Tall tussock grassland.

Rainfall: 40".

Parent material: Greywacke colluvium with an addition of some wind-blown fines.

AB 0 -2½" Brown (1Y4/3), dry 2.5Y6/2; loam; very friable; weak root binding; moderate fine crumb and weak fine granular; many roots; few very fine cast granules; very porous; scattered stones on the surface; indistinct boundary -

(B) 2½- 7" Dark olive brown (2.5Y4/4), dry 2.5Y6/2; silt loam; very friable; weak nutty breaking to moderate medium and fine crumb; many roots; very porous; few angular greywacke stones, especially towrds base of horizon; distinct and irregular boundary to -

B_3 7 - 9" Olive brown to dark olive brown (2.5Y4.5/4); stony silt loam; distinct stoneline of weakly weathered angular greywacke stones in loose matrix; some stones penetrating into the horizon below; distinct and irregular boundary to -

u(B) 9 - 14" Olive brown (2.5Y5/4), dry 5Y7/3; slightly stony sandy loam; friable; weak to moderate fine nutty tending to blocky and some fine crumb; rare roots; few to common fine pores; slightly stony angular weakly weathered greywacke stones; irregular boundary to -

uBC 14" + Light yellowish brown (2.5Y5.5/4), dry 5Y7/3; very stony loam; firm tending to be compact; weak fine nutty tending to blocky and some weak to moderate fine crumb; few to common fine pores; very stony weakly weathered angular greywacke stones and small boulders.

(B) and uBC give strong positive reaction to the allophane field test.

Technical classification: Very strongly enleached lithi-eldefulvic soil from weakly argillised greywacke colluvium and sub-moderately argillised loess.

Profile No: MC 84 Soil Type: Puketeraki hill soil (silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
AB	0-2	5.2	3.7	0.21	18	11.32	0.56	5	0.3	0.1	0.20	0.1
B	3-7	5.1	5.2	0.27	19	11.47	0.50	4	0.2	0.1	0.14	0.1
uB	9-12	5.3	2.3	0.12	19	11.05	0.31	3	0.2	0.0	0.04	0.1
uBC	14-16	5.1	0.7	0.03	23	5.42	0.37	7	0.2	0.0	0.05	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
AB	233	567	106	906
B	105	630	263	1024
uB	86	422	148	656
uBC	306	199	141	646

Whole Soil %		% On fine earth		
Gravel	Stones	Sand	Silt	Clay
8	-	55	27	18
37	30	48	29	22
21	22	71	24	10
14	14	75	18	7

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
AB	C	c	C	C	C	-	c	P	c	c
B	C	c	C	C	-	c	c	P	S	c
uB	C	c	C	C	-	C	c	P	S	S
uBC	C	C	C	S	-	a	c	P	S	S

Profile no: MC.77.

Soil type: Tekoa steepland soil (stony silt loam), Tekoa series.

Location: About $1\frac{1}{4}$ miles upstream from gorge on eastern boundary.

Map sheet: S.91. Grid reference: 56900460.

Terrain: Steep. Slope: 31^{o}.

Landform: Lower mid-slope on steeply sloping side of high ridge.

Aspect: NW. Elevation: 2790' asl.

Drainage - site: Very well drained - shedding site.

- internal: Very well drained.

Vegetation - present: Sweet vernal Pimelia sp. hard and snow tussock, matagouri and mouse ear.

- past: Podocarp forest followed by tall tussock.

Rainfall: 34".

Parent material: Greywacke colluvial debris over weathering greywacke and argillite.

A_{11} 0 -$2\frac{1}{2}$" Very dark greyish brown (10YR3/2.5); gravelly loam to silt loam; very friable; weak to moderate fine and medium granular; and fine crumb; abundant roots; few casts; very porous; stony moderately weathered angular greywacke gravels; indistinct boundary to -

A_{12} $2\frac{1}{2}$-$6\frac{1}{2}$" Very dark brown (10YR3/2.5), dry 2.5Y5/2; stony slightly gritty silt loam; very friable to friable; weak to moderate medium and fine crumb; and some medium and fine granular; many roots; common cast granules; porous; stony moderately weathered angular gravels and small greywacke stones; indistinct boundary to -

AB $6\frac{1}{2}$-10" Very dark brown (10YR3/3), dry 2.5Y5/2; stony slightly gritty silt loam; friable to very friable; weak to moderate medium and fine crumb and granular; many roots; few casts; very porous; stony to very stony moderately weathered gravel and small greywacke stones; indistinct and irregular boundary to -

BC 10-16"+ Brown (10YR4/3), dry 2.5Y5/2; extremely stony silt loam; very firm to firm; weak to moderate fine crumb; many roots; rare casts; porous; extremely stony moderately weathered greywacke and argillite gravel and stones; giving way to moderately weathered greywacke and argillite below 16-18".

Technical classification: Moderately enleached intergrade clini-lithi-eldefulvic to fulvi-clini-lithic soil from sub-moderately argillised greywacke colluvium over sub-moderately argillised greywacke and argillite.

Profile No: MC 77 Soil Type: Tekoa steepland soil(sty silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-4	5.4	4.2	0.26	16	15.59	5.39	35	3.6	1.2	0.42	0.1
AB	7-10	5.8	5.0	0.33	15	17.50	8.17	48	6.1	1.3	0.70	0.1
BC	12-15	5.8	4.4	0.29	15	17.70	9.37	53	7.2	1.4	0.69	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	489	648	292	1429
AB	330	859	459	1684
BC	310	930	294	1534

Whole Soil %		%On fine earth		
Gravel	Stones	Sand	Silt	Clay
17	-	53	30	19
41	21	nd	nd	nd
45	45	56	29	15

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	C	C	C	C	-	-	C	P	S	c
BC	C	a	C	c	-	-	C	P	S	c

Profile no: MC.44.

Soil type: Kaikoura hill soil (stony silt loam), Kaikoura series.

Location: On Mowbray watershed 30 yards NW of Trig. B.

Map sheet: S.90. Grid reference: 54500550.

Terrain: Moderately sloping ridge top. Slope: 10^{o}.

Landform: Edge of narrow ridge top in steep country.

Aspect: North. Elevation: 4350' asl.

Drainage - site: Very well drained - shedding site.
- internal: Very well drained.

Vegetation:- present: Tall tussock and rare Celmisia sp.
- past: Tall tussock grassland.

Rainfall: 40".

Parent material: Weathering greywacke in place.

A_{11}	0 - 2"	Very dark brown (10YR3/3), dry 10YR4.5/1; stony silt loam; very friable; fluffy and powdery when dry; very weak fine crumb; abundant fine roots; very porous; stony moderately weathered angular small stones to boulders; indistinct boundary to -
A_{12}	2 -6½"	Very dark greyish brown (10YR3/2), dry 2.5Y5/2; stony silt loam; very friable (peds friable to very friable); moderate fine to coarse granular and fine crumb; many roots; rare casts; rare channels; porous; stony moderately weathered angular small stones to boulders; indistinct boundary to -
AB	6½-12"	Very dark brown (10YR3/3), dry 2.5Y5/2; stony silt loam; very friable; weak to moderate medium and fine granular and fine crumb; many roots; common casts as inclusions from A12; rare channels; porous; stony moderately weathered angular small stones to boulders; distinct boundary-
BC	12-16"	Yellowish brown (1Y5/4), dry 5Y7/3; very stony silt loam; very friable; weak very fine nutty and fine crumb and moderate to weak fine granular; common roots; few casts; few channels; common fine pores; very stony moderately weathered angular small stones to boulders becoming continuous below 16".

Abnormally high base status of the A horizon may be due to derivation from the large number of sheep droppings on the surface in this region.

Technical classification: Strongly enleached lithi-eldefulvic soil from moderately argillised greywacke.

Profile No: MC 41 Soil Type: Kaikoura hill soil (stony silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq % Ca	Mg	K	Na
A_{11}	0-2	5.9	14.1	0.65	22	33.62	25.94	77	15.5	6.5	3.81	0.1
A_{12}	2-7	5.6	9.4	0.51	18	18.82	4.93	26	1.5	1.6	1.74	0.1
AB	7-12	5.3	7.5	0.39	19	16.65	2.76	17	0.7	0.7	1.35	0.0
BC	12-16	5.3	4.5	0.24	19	13.54	0.72	5	0.1	0.1	0.43	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm	Whole Soil % Gravel	Stones	% On fine earth Sand	Silt	Clay
A_{11}	850	952	79	1881	21	15	nd	nd	nd
A_{12}	311	898	26	1225	8	-	48	33	19
AB	256	804	11	1131	4	24	50	33	16
BC	73	608	62	743	18	36	46	32	22

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_{12}	C	S	a	a	-	-	-	P	s	S
AB	S	S	C	a	C	-	-	P	S	S
BC	c	c	a	C	a	-	P	P	S	S

Profile no: MC.83.

Soil type: Kaikoura hill soil (stony silt loam), Kaikoura series.

Location: About ½ mile north of Lookout Peak on the eastern watershed

Map sheet: S.91. Grid reference: 57600315.

Terrain: Moderately steep. Slope: 13^{o}.

Landform: Hilly ridge crest with steeply sloping eroded sides.

Aspect: North. Elevation: 4300'.asl.

Drainage - site: Very well drained - shedding site.

- internal: Well drained.

Vegetation - present: Celmisia sp. blue tussock and regenerating snow tussock following burning.

- past: Tall tussock grassland.

Rainfall: 38".

Parent material: Greywacke colluvial debris over greywacke.

A_{11} 0 - 2" Dark greyish brown (10YR4/2.5), dry 2.5Y5/2; slightly gritty silt loam; very friable to loose; moderate medium and fine granular and weak to moderate crumb; abundant roots; few casts; few pores; a wash of very weakly weathered greywacke gravels on the surface; indistinct boundary to -

A_{12} 2 -4½" Very dark greyish brown (2.5Y3/2); slightly gritty silt loam; friable; moderate medium and fine fitting granular and very fine nutty with weak to moderate fine crumb; abundant roots; common casts; porous; few angular weakly to moderately weathered greywacke gravels; distinct boundary to -

AB 4½- 7" Dark brown (10YR3/3), dry 2.5Y5/2); very stony silt loam; friable to firm; weak to moderate fine nutty with fitting fine and medium granular and some weak fine crumb; abundant roots; common finecasts; porous; stony angular moderately to strongly weathered greywacke gravels and stones; distinct boundary to -

BC 7 - 9" Yellowish brown (10YR5/5), dry 2.5Y7/4; extremely stony sandy loam; firm to very firm; slightly compact; weak fine crumb; few roots; few casts; porous; extremely stony angular stones and boulders of moderately to strongly weathered greywacke; becoming completely stony below 10".

AB has weak reaction and BC has very strong rapid reaction to allophane field test.

Technical classification: Very strongly enleached intergrade lithieldefulvic to fulvi-lithic soil from sub-moderately argillised greywacke colluvium on moderately argillised greywacke.

Profile No: MC 83 Soil Type: Kaikoura hill soil (stony silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq % Ca	Mg	K	Na
A_1	1-3	5.0	8.6	0.38	23	19.99	2.43	12	1.3	0.7	0.44	0.1
AB	4-7	4.9	7.5	0.30	25	16.18	0.86	5	0.2	0.2	0.32	0.1
BC	7-9	5.1	5.6	0.25	22	17.34	0.38	2	0.1	0.1	0.12	0.1

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	156	562	165	883
AB	94	511	173	778
C	114	301	274	689

Whole Soil % Gravel	Stones	% On fine earth Sand	Silt	Clay
6	-	47	29	24
16	53	nd	nd	nd
25	55	54	26	20

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	C	c	a	C	c	-	C	P	c	c
BC	c	C	C	A	-	-	C	P	S	S

Profile no: MC.70.

Soil type: Kaikoura steepland soil (stony silt loam)
Kaikoura series.

Location: About 1½ miles north of Fiery Top on eastern watershed.

Map sheet: S.91. Grid reference: 57300450.

Terrain: Steeply sloping. Slope: 26°.

Landform: Upper mid-sl pe on strongly to steeply sloping side of high ridge.

Aspect: NNW. Elevation: 3350' asl.

Drainage:- site: Very well drained - shedding site.
- internal: Very well drained.

Vegetation - present: Snow, hard and blue tussocks, sweet vernal, and scattered Celmisia sp. and Carmichaelia sp.
- past: Tall tussock grassland.

Rainfall: 35 - 40".

Parent material: Greywacke colluvium.

A_{11} 0 -3½" Very dark greyish brown (10YR3/2), dry 10YR4/3; stony gritty silt loam; loose to very friable; very fluffy when dry; weak fine granular and fine crumb; abundant roots; rare fine casts; porous; stony angular moderately weathered greywacke gravel and small stones; indistinct boundary to -

A_{12} 3½- 7" Olive brown (1Y4/3- slightly dry); stony gritty loam; loose to very friable (peds very friable); fluffy when dry; weak fine crumb and fine granular; many roots; few fine casts; porous; stony angular moderately weathered gravel and small stones; indistinct -

AB 7 -13" Olive brown (2.5Y4/3); dry 2.5Y4.5/2; stony gritty loam; friable (peds friable to firm); weak to moderate fine nutty and moderate to strong fine granular; many roots; common casts as inclusions of A12; few fine channels; common pores; stony angular moderately weathered greywacke gravel and stones; indistinct boundary to,-

BC 13-18" Olive brown (2.5Y4/4), dry 10YR5/4; extremely stony gritty loam; friable; moderate fine nutty and weak fine crumb; common fine roots; few fine channels; few casts as inclusions from AB; common pores; extremely stony angular moderately weathered gravel to large stones; merging to -

C 18-24"+ Light olive brown (2.5Y5/6), extremely stony gritty silt loam; firm - moderately compact; (peds very friable) very weak fine crumb; few roots; extremely stony angular moderately weathered greywacke stones and boulders.

Technical classification: Strongly enleached clini-lithi-eldefulvic soil from weakly and moderately argillised greywacke colluvium.

Profile No: MC 70 Soil Type Kaikoura steepland soil (sty silt loam)

	Depth inches	pH	C %	N %	C/N	C.E.C. meq. %	Σ Cations.	B.S. %	Exch. Cations. meq %			
									Ca	Mg	K	Na
A_1	1-5	5.7	8.2	0.50	16	18.07	4.91	27	3.5	0.8	0.47	0.2
AB	9-12	5.6	7.1	0.40	18	15.54	3.01	19	2.1	0.5	0.38	0.1
BC	13-15	5.4	5.1	0.30	17	11.14	0.93	8	0.6	0.1	0.12	0.1
C	20-23	5.4	3.9	0.25	16	17.08	3.11	18	2.0	0.6	0.25	0.3

	Pa ppm	Po ppm	Pf ppm	Pt ppm
A_1	376	735	323	1434
AB	191	771	122	1084
BC	161	581	259	1000
C	158	562	249	969

Whole Soil %		% On fine earth		
Gravel	Stones	Sand	Silt	Clay
36	19	56	28	17
34	16	nd	nd	nd
28	13	56	29	16
15	77	51	29	20

	chlorite	illite (mica)	interlayered hydrous micas	vermiculite 1	vermiculite 2	montmonllonite	metahalloysite	gibbsite	quartz	feldspar
A_1	C	c	C	C	-	-	-	P	C	C
BC	A	c	C	c	-	-	-	P	c	c
C	C	c	C	a	-	-	-	P	c	c

Profile No: MC.42.

Soil type: <u>Kirkliston silt loam</u> (Kirkliston series)

Location: About ½ mile north of Trig.B on the western watershed.

Map sheet: S.90. Grid reference: 53150680.

Terrain: Undulating to rolling. Slope: 3^{o} (varying to 12^{o})

Landform: Remnant of old, now deeply dissected, peneplain.

Aspect: NW. Elevation: 3280' asl.

Drainage - site: Well drained but may tend to accumulate run-off.

- internal: Moderately well drained.

Vegetation:- present: Snow, hard and blue tussocks, <u>Carmichaelia sp.</u> and mouse ear.

- past: Probably open Podocarp forest followed by tall tussock grassland.

Rainfall: 35".

Parent material: Weathering greywacke in place with accumulation of windblown and washed fines.

A_{11} 0 -1½" Dark greyish brown (10YR3.5/2); silt loam; very friable to loose (peds friable); moderate root binding; weak to moderate fine granular; and very fine nutty; some weak fine crumb; abundant fine roots; common small casts; porous; merging and indistinct boundary to -

A_{12} 1½- 4" Dark brown (10YR4/3); silt loam; very friable to friable (peds firm); strong fine and medium granular and very fine nutty; abundant roots; many inclusions of A11 and AB; common channels; few fine pores; indistinct -

AB 4 - 7" Brown(10YR4/3); heavy silt loam; very friable to friable; (peds firm); moderate medium and fine nutty breaking to fitting fine and medium granular; many roots; many casts as inclusions of A12; common channels; few fine pores; distinct boundary to -

B_1 7 -10" Yellowish brown(10YR5/5); heavy silt loam; very friable to friable (peds friable to firm); moderate medium and fine nutty breaking to moderate to strong medium and fine fitting granular; many roots; many casts as inclusions of AB; common channels; few to common fine pores; few subangular strongly weathered greywacke gravels; distinct boundary to -

B_2 10-13" Brownish yellow (10YR6.5/5); heavy silt loam; friable (peds friable to firm); moderate fine nutty and some fine granular; common roots; few cast inclusions of B1; few channels; few to common pores; few very thin discontinuous clayskins on a few ped faces; rare fine yellow mottles from decomposing stones; rare fine subangular strongly weathered greywacke gravels; merging to -

C 13-20"+ Yellow (10YR7/8); heavy silt loam; friable to firm; weak to moderate medium and fine nutty; few roots; few channels; discontinuous clay-skins on peds and in some channels; common to few pores; rare fine subangular strongly weathered greywacke gravel.

Technical classification: Very strongly enleached, weakly clay illuvial eldefulvic soil from strongly argillised greywacke and moderately argillised greywacke loess.

APPENDIX 2

RESULTS OF QUICK-TEST ANALYSES, 0 - 6" OF SELECTED SOIL TYPES

Soil	pH	Ca	K	Truog P	Bray P	Location
Tasman silt loam	5.4	1	3.5	3	25.5	Orari fan
Tasman sandy loam	6.0	7	2	13	5.5	Mowbray fan
Ashwick silt loam	5.6	4	16	9	82.5	Orari fan
Ashwick sandy silt loam	5.8	2	5.5	4.5	40	Mowbray fan
Mowbray silt loam	5.5	2	5	8	18	Orari fan
Mowbray silt loam	5.6	3	2	14	18	Mowbray fan
Mowbray stony silt loam	5.6	1	2	4.5	47	Mowbray fan
Meikleburn silt loam	5.5	2	9.5	8	55	Orari fan
Meikleburn silt loam	5.5	4	7.5	8	44	Mowbray fan
Meikleburn silt loam	5.6	2	2	2	11	Mowbray fan
Meikleburn silt loam	5.6	6	4	4	12	Mowbray fan
Wakanui silt loam	5.9	10	3	3	4	Meikleburn floodplain
Wakanui silt loam	5.8	9	4.5	5	7.5	Meikleburn floodplain
Wakanui sandy silt loam	5.9	7	4.5	4	3	Meikleburn floodplain
Taitapu silt loam	5.9	8	3	3	3.5	Meikleburn floodplain
Sherwood silt loam	5.6	5	7.5	4	14	Meikleburn fan
Sherwood silt loam	5.6	5	6	5.5	25	Meikleburn fan
Sherwood silt loam	5.7	3	11.5	5	34	Orari fan
Clayton silt loam	5.4	4	3.5	1	4.5	Tripp Pass
Clayton silt loam	5.3	4	5.5	2	5.5	Meikleburn homestead
Skipton silt loam	5.8	5	10	3	13	Profile MC 89
Tengawai silt loam	5.5	4	6.5	2	6	Tripp Pass
Tengawai stony silt loam	5.8	5	5	4.5	19.5	Trig M.

Quick-test analyses carried out by Dept. of Agriculture, Invermay.

APPENDIX 3

WEIGHT OF PHOSPHORUS AND PHOSPHORUS FRACTIONS IN HORIZONS OF SELECTED PROFILES

(weights expressed as Kg/hectare/horizon inch)

Horizon.	Thickness inches	Pa	Pf	Po	P_T	Pa as % Pinorg.
M.C. 53 Sherwood silt loam.						
A_1	5	70	31	204	305	69
AB	3	60	51	171	282	54
B_{21}	5	82	49	170	301	63
B_{22}	5	59	38	84	181	61
D	6	100	10	59	169	91
M.C. 79 Opuha silt loam (hill soil)						
A_1	6	39	20	177	236	66
B_1	4	26	34	120	180	44
B_2	6	23	18	125	166	56
BC	6	22	11	53	86	67
D	2	23	28	49	100	44
M.C.89 Skipton silt loam						
A_1	8	53	22	155	230	71
AB	3	43	22	132	197	66
B_2	5	26	6	62	94	82
B_3	4	58	18	37	113	77
D	4	39	50	61	150	44
M.C. 28 Kakahu silt loam						
A_1	6	46	7	169	222	88
B_1	3	32	20	154	206	62
B_2	4	24	4	116	144	87
B_3	11	29	27	124	180	51
D	3	14	24	60	98	37
M.C. 81 Kakahu silt loam (hill soil)						
A_1	9	42	36	95	173	54
AB	4	39	18	137	194	69
B_2	7	99	52	67	218	65
BC	4	135	41	91	267	77

M.C. 44 Tengawai silt loam (hill soil)						
A_1	10	36	18	174	228	67
AB	4	16	7	120	143	71
B_2	6	19	18	177	214	52
D	4	30	35	88	153	46
M.C. 72 Tengawai stony silt loam (hill soil)						
A_1	6	33	18	103	154	65
B_1	6	36	44	153	233	45
B_2	6	43	40	141	224	52
BC	6	45	58	195	298	44
M.C. 85 Tengawai stony silt loam (hill soil)						
A_1	6	95	35	164	294	73
AB	3	58	13	185	256	82
B_2	7	42	68	247	357	38
BC	8	51	126	142	319	29
M.C. 64 Lookout stony silt loam (steepland soil)						
A_1	8	43	35	176	254	56
AB	3	34	16	166	216	67
BC	6	48	28	135	231	63
uB	6	65	40	144	249	62
uBC	8	101	29	126	256	78
M.C. 69 Puketeraki stony silt loam (steepland soil)						
A_1	6	33	58	93	184	36
AB	4	27	43	132	202	38
(B)	4	16	21	126	163	42
BC	10	18	6	114	138	74
M.C. 84 Puketeraki silt loam (hill soil)						
AB	$2\frac{1}{2}$	66	30	160	256	69
(B)	$4\frac{1}{2}$	14	36	85	135	28
uB	7	18	30	87	135	37
uBC	2	120	55	78	253	68

1. Texture:

gravel	g	stony loam	stl
very coarse sand	vcos	silt	si
coarse sand	cos	silt loam	sil
sand	s	clay loam	cl
fine sand	fs	silty clay loam	sicl
very fine sand	vfs	sandy clay loam	scl
loamy coarse sand	lcos	fine sandy clay loam	fscl
loamy sand	ls	coarse sandy clay loam	coscl
loamy fine sand	lfs	stony clay loam	stcl
sandy loam	sl	silty clay	sic
fine sandy loam	fsl	clay	c
very fine sandy loam	vfsl	muck	m
gravelly sandy loam	gsl	peat	p
loam	l	mucky peat	myp
gravelly loam	gl	peaty muck	pym

2. Consistence:

Wet Soil -		Moist Soil -	
non-sticky	wso	loose	ml
slightly sticky	wss	very friable	myfr
sticky	ws	friable	mfr
very sticky	wvs	firm	mfi
non-plastic	wpo	very firm	mvfi
slightly plastic	wps	extremely firm	mefi
plastic	wp	Cementation -	
very plastic	wvp	weakly cemented	cw
		strongly cemented	cs
		indurated	ci

Structure:

Size -		Shape -	
very fine	vf	platy	pl
fine	f	prismatic	pr
medium	m	columnar	cpr
coarse	c	blocky	bk
very coarse	vc	angular blocky	abk
		subangular block	sbk
Grade -		granular	gr
structureless	0	crumb	cr
weak	1	single grain	sg
moderate	2	massive	m
strong	3		

Example: moderately to strongly developed medium and fine subangular blocky = mf2-3sbk

4. Pores:

Few	(1 - 3/sq. inch or about 6.5 sq. cm.)	1P
Many	(4 - 14/sq. inch)	2P
Abundant	(more than 14/sq. inch)	3P

5. Clayskins:

Patchy clayskins on few peds and in some pores	1C
Discontinuous clayskins on some peds and in many pores	2C
Almost continuous clayskins on most peds and in most pores	3C

6. Mottles: Roots: Channels: Casts: Nests:

Abundance -		Contrast -	
few	f	faint	f
many	m	distinct	d
abundant	a	prominent	p
profuse	p		
Size -			
fine	1		
medium	2		
coarse	3		

Example: few medium prominent strong brown mottles = f2p7.5YR5/6.

7. Horizon boundaries:

Sharp	sh	Irregular	ir
Distinct	ds	Merging	mg
Indistinct	id		
Diffuse	df		

DESCRIPTION SHEET PIT/COMPOSITE/AUGER

APPENDIX 4. Profile Description Sheet

Field No.	Rainfall	Location	Vegetation - Past	Cul./Uncul./Vir.
Lab. No.	Grid Ref.	County	Present	Topdr./Untopdr.

Landform	Elevation	Slope Tern Class	Aspt.	Drainage	Erosion	Parent material/rock

Horizons		Sample Depth & No.	Colour moist/dry	Texture	Consistence	Structure	Roots (R), Casts (Cts), Channels (Ch), Nests (N)	Clayskins & Pores C & P	Identifiable Minerals Insects etc.	Mottles	Stones & Concretions	Boundary
Symbol	Thickness											

Notes	Type	Tent/Est'd
	Phase/Variant	Set

Surveyor	Date	Classification